CORPS OF ENGINEERS
U. S. ARMY

COMPREHENSIVE REPORT
INVESTIGATION OF MILITARY CONSTRUCTION IN ARCTIC AND SUBARCTIC REGIONS
1945-1948

MAIN REPORT

PREPARED BY
ST. PAUL DISTRICT
CORPS OF ENGINEERS
FOR
OFFICE OF THE CHIEF OF ENGINEERS
AIRFIELDS BRANCH
ENGINEERING DIVISION
MILITARY CONSTRUCTION

JUNE 1950

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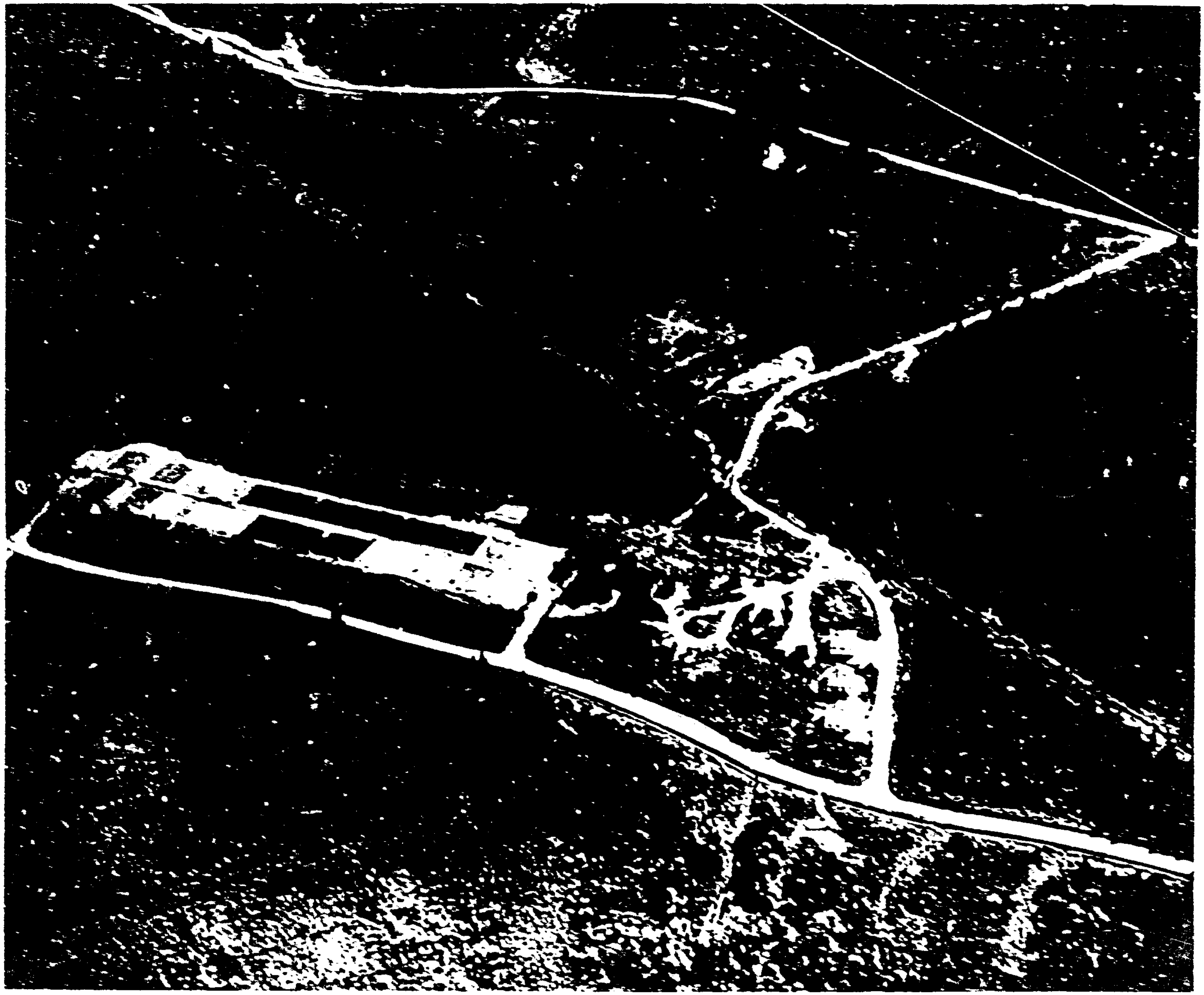

Fairbanks Research Area, Fairbanks, Alaska

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Synopsis

The problems of location, design, construction and maintenance of military airfields and other engineering works in arctic and subarctic regions are peculiar to those regions. The purpose of this investigation is to determine the methods and procedure to be used in the solution of these problems.

Observations of existing structures have been made at various airfields in Alaska since 1945, and additional test structures were constructed near Fairbanks in 1946 and 1947 on which observations are being made. Construction and installation of equipment for observation of ground temperatures at certain weather stations throughout Alaska have been completed and observations are being made. The observations have resulted in the formulation of certain conclusions regarding the structures tested.

Laboratory research has been carried on at the University of Minnesota to determine the thermal properties of soils and certain insulating materials. Purdue University has been engaged in developing procedures for locating permafrost and determining the kind of arctic and subarctic soils from aerial photographs. Library research is being conducted to locate and translate, where necessary, literature pertaining to permafrost. The results of geophysical exploration, using electrical resistivity methods, do not justify further work on permafrost until improved equipment is developed. Special equipment has been developed, where necessary, to achieve the purpose of the investigation. Studies have been made of the data collected from the various phases of the investigation.

The investigations at the Fairbanks Research Area, Alaskan weather stations, library research, and aerial photographic reconnaissance studies should be continued. The investigation at Northway should be discontinued when the ground temperatures under the hangar have stabilized.

COMPREHENSIVE REPORT

INVESTIGATION OF MILITARY CONSTRUCTION
IN ARCTIC AND SUBARCTIC REGIONS

I Introduction

1. AUTHORIZATION. The project for the investigation of military construction in arctic and subarctic regions was authorized by the Office, Chief of Engineers in a letter to the Division Engineer, Upper Mississippi Valley Division, SPENM (2 February 1945), Subject: "Investigation of Airfield Construction in Arctic and Subarctic Regions". The St. Paul District was designated as the Investigational Agency, with supervision by the Division Engineer to consist of inspections and reviews of programs, as deemed necessary, decisions with respect to major policies, and reviews of special and periodic reports. Direct correspondence between the Investigational Agency and the Office, Chief of Engineers was authorized. Specific instructions to submit this report are contained in a letter from the Office, Chief of Engineers, ENGER (25 October 1948) to the District Engineer, St. Paul District, Subject: "Comprehensive Report, Investigation of Airfield Construction in Arctic and Subarctic Regions, dated January 1948".

2. PURPOSE. The purpose of the investigation is to determine design methods and procedures to be used in military construction in arctic and subarctic regions. Information as it is acquired will be used as follows:

a. To supplement or enlarge Technical Bulletin TB 5-255-3.

b. To supplement Technical Manual TM 5-255 when sufficient information has been accumulated.

c. To provide a chapter on permafrost construction in the Engineering Manual.

d. To prepare guide construction specifications.

3. SCOPE. This report presents a summary of the data and results obtained from the beginning of the investigation. It includes results of tests at Northway Airfield, Eielson Air Force Base, Ladd Air Force Base, Alaska, and at the Fairbanks Research Area near Fairbanks, Alaska; data on construction equipment and methods; data collected at Alaskan weather stations; laboratory research on tests of thermal properties of soils and insulating materials; interpretation of frozen and unfrozen ground conditions from aerial photographs; library research; geophysical exploration methods; theoretical studies; and field tests of model structures. A map of Alaska indicating points at which investigations were made, as well as other points, is shown on Plate 1.

4. DEFINITIONS.

Active zone -- the entire layer of ground above the upper surface of the permafrost layer, most of which freezes and thaws every year.

Adfreezing force -- the grip of frozen ground on a pile or foundation wall.

Arctic -- relating to, or characteristic of, the North Pole or the region near it, the frigid zone within the Arctic Circle.

Base -- the course of specially selected soils, minerals, aggregates or treated soils placed and compacted on the natural or compacted subgrade.

British thermal unit (Btu) -- the amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit at 58 degrees Fahrenheit.

Degree-day -- each degree in any one day that the daily mean air temperature varies from 32° F is called a degree-day. The difference between the daily mean temperature and 32° F equals the degree-days for that day. The degree-days are minus when the daily mean temperature is below 32° F and plus when above. A cumulative degree-days-time curve is obtained by plotting cumulative degree-days against time.

Density (d) -- the unit dry weight in lb per cu ft.

Diffusivity -- an index of the facility with which a material will undergo temperature change. It is equal to thermal conductivity divided by the product of specific heat and density.

Film conductance -- synonym for surface conductance.

Freezing index (F_a) -- the number of degree-days between the highest and lowest points on the cumulative degree-days-time curve for one freezing season. It is used as a measure of the combined duration and magnitude of below-freezing air temperatures occurring during any given freezing season.

Freezing point of soil moisture -- the same as the freezing point of water (32° F). For soils having a texture finer than that of silts and for soils having relatively low moisture content, the freezing point is depressed below 32° F.

Freezing season -- that period of the year during which daily mean air temperatures below 32° F occur. It starts with the first day in the fall season and ends with the last day in the spring season, on which the daily mean air temperature is below 32° F.

Frost action -- a general term used in reference to freezing of moisture in materials and the resultant effects on these materials and structures of which they are a part.

Frost heave -- the raising of the ground surface or pavement due to the accumulation of ice lenses. The amount of heave in most soils is approximately equal to the cumulative thickness of ice lenses.

Frost-susceptible soil -- a soil in which frost action is possible. Any soil which contains three percent or more by weight of soil grains smaller than 0.02 mm diameter is generally considered susceptible to frost action.

Frost zone -- the top layer of ground subject to seasonal freezing and thawing. Where seasonal freezing penetrates to the upper surface of the permafrost layer, the frost zone and the active zone are identical.

Frozen soil -- frozen soil is referred to in this report as follows:

(a) Homogeneous frozen soil. -- a soil in which all the water in the soil is frozen within the natural voids existing in the soil, without observable

accumulation of ice crystals or ice lenses of frost forms exceeding in volume such natural void spaces.

(b) Stratified frozen soil. -- a soil in which a part of the water in the soil is frozen in the form of observable ice crystals and ice lenses, occupying space in excess of the original soil voids.

Ground isotherm -- a line connecting points of equal temperature in the ground at a given time.

Ground polygons -- generally the surface manifestation of the presence of ground ice wedges inclosing fine-grained soil in polygonal shapes.

Groundwater -- water within the earth. It may exist above, within, or below the permafrost layer, depending on geologic and physiographic features, climate, and seasonal weather variations. Since it may thaw permafrost, it is an important factor to consider.

Groundwater table -- the free water surface nearest to the ground surface.

Ice crystals -- the formation of ice particles found in the pores of homogeneous frozen soil.

Ice segregation -- in soils is the growth of bodies of ice during the freezing process, most commonly as ice lenses or layers oriented normal to the direction of heat loss, but also as veins and masses having other patterns.

Latent heat of fusion (L) -- the quantity of heat necessary to change one pound of a solid to a liquid with no temperature change. For ice the latent heat of fusion is 143.4 Btu per lb.

Non-frost-susceptible materials -- materials such as crushed rock, gravel, sand, slag, cinders, or any other cohesionless material in which the formation of detrimental ice lenses is not possible.

Permafrost -- permanently frozen subsurface material not subject to seasonal freezing and thawing.

Specific heat (c) -- the number of Btu's necessary to raise the temperature of one pound of a substance one degree Fahrenheit.

Subarctic -- those regions immediately outside of the Arctic Circle, or those which for various reasons, as altitude, etc., are similar to arctic regions in climate and conditions of life.

Subgrade -- the natural soil in place or fill material upon which a base, pavement, or footing is constructed.

Surface conductance (f) -- the time rate of heat flow from a square foot of surface to the air per degree difference in temperature between the surface and the air.

Surface resistance -- the reciprocal of surface conductance.

Temperature gradient -- the rate of change of temperature between two points.

Temperature test hole -- a drill hole in which ground temperatures are observed by means of mercury thermometers, thermocouples, or electrical resistance thermometers.

Thawing index (I_a) -- the number of degree-days between the lowest and highest points on the cumulative degree-days-time curve for one thawing season. It is used as a

measure of combined duration and magnitude of above-freezing air temperatures occurring during any given thawing season.

Thawing season -- that period of the year during which daily mean air temperatures above 32° F. occur. It starts with the first day in the spring season and ends with the last day in the fall season, on which the daily mean air temperature is above 32° F.

Thermal conductance (C) -- the time rate of heat flow through a substance for an area of one square foot and a difference of temperature of one degree Fahrenheit between surfaces.

Thermal conductivity (k) -- the time rate of heat flow in Btu per hour through a substance for an area of one square foot and with a temperature gradient of one degree Fahrenheit per inch of thickness.

Thermal regime -- the prevailing ground temperature condition.

Thermal resistance (R) -- the reciprocal of thermal conductance.

Thermal resistivity (r) -- the reciprocal of thermal conductivity.

Utilidor -- an insulated and heated conduit placed in the ground or supported above the ground to protect water, steam and sewage pipes from freezing.

Volumetric heat capacity -- the number of Btu's necessary to raise the temperature of one cubic foot of a material one degree Fahrenheit.

For dry soils, cd

For wet soils, $d(c + 1.0 \frac{w}{100})$

For wet, frozen soils, $d(c + 0.5 \frac{w}{100})$

Volumetric latent heat ($Lwd = 1.434\ wd$) -- the number of Btu's necessary to melt the ice in one cubic foot of soil.

Water content (w) -- percentage of water in a substance based on dry weight of the substance.

5. ENGINEERING PROBLEMS. The removal of natural vegetation insulation on the ground surface in connection with construction operations and the introduction of artificial heat into the ground under buildings will, in time, melt the permafrost. Failure of structures placed on permanently frozen, fine-grained soil, which is unstable when thawed, is likely to occur when the water released from the melting ice lenses flows out of the loaded soil. Settlement of a building may be cumulative over a period of many years as additional heat continues to melt the frozen ground.

II Airfield Site Studies

Northway Airfield, Alaska

6. PURPOSE. The investigation at Northway Airfield, Alaska was initiated for the purpose of collecting basic physical data on soil characteristics, ground temperatures,

groundwater, foundation designs, and other factors as they affect facilities at this site, with particular reference to permanently frozen ground and associated problems. Detailed descriptions and data concerning the Northway Airfield are contained in Appendix I.

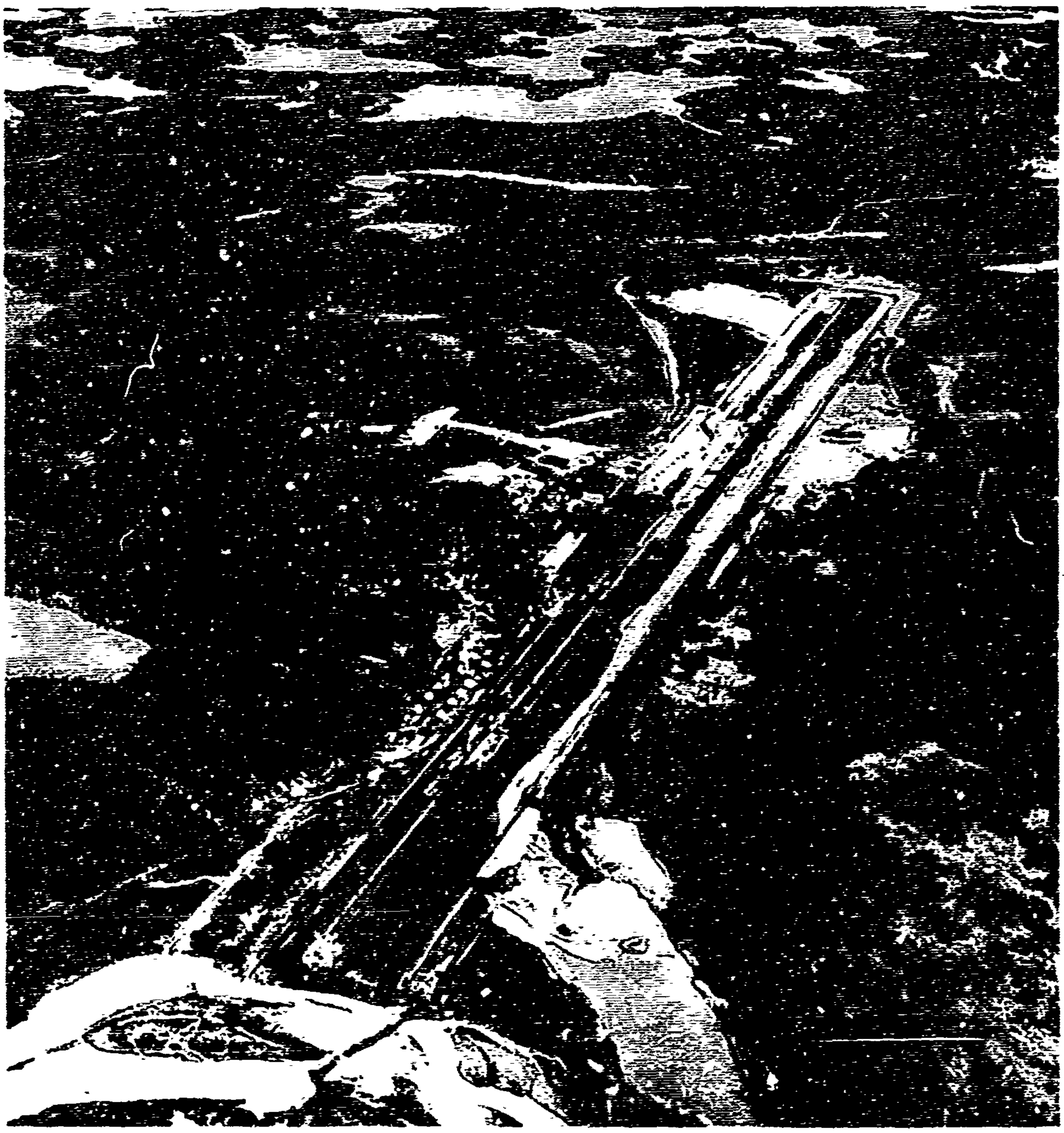


Figure 1. Northway Airfield, Alaska, June 1946

7. GENERAL CONDITIONS. Northway Airfield is located in the flood plain of the

Nabesna River, about 230 miles southeast of Fairbanks and about 30 miles west of the Canada-Alaska boundary. See Plate 2 and Figure 1. The terrain surrounding the airfield is relatively flat except for numerous small lakes. The soil is predominantly sand with shallow layers of silt near the surface. The surface soil is generally covered with thick moss and peat. Permafrost occurs in islands at this site probably as a result of meanderings of streams in the area. The mean annual temperature and precipitation for the years 1943 to 1947, inclusive, were 23.8° F and 12.52 in., respectively. The runway at Northway Airfield is 7500 ft long and consists of a 7-in. asphalt emulsion pavement on a 3.5-ft-thick base course of sand and gravel. Several types of foundations were used under the various buildings at this airfield. Most of the foundations were spread concrete footings resting on the ground. A few foundations were composed of treated timber piling supporting either beams or concrete slabs. A third type of foundation consisted of a sandwich comprised of a sand layer on the natural ground, a reinforced concrete slab, and a sand and gravel layer on which the spread footings and floor were placed.

8. EXPLORATIONS AND TESTS. A number of core borings were made along the runway and in or adjacent to several buildings for the purpose of recovering frozen samples of natural soil with a view to determining its density, moisture content, and other physical properties. Because of the sandy and frequently unfrozen character of the soil, it was extremely difficult to recover satisfactory samples of soil by core drilling at this site. During the summer, artificial freezing methods were used with some success to recover samples of thawed sand. Ground temperature observation equipment consisting of either mercury thermometers or thermocouples was installed in the core drilled holes and observations made at weekly intervals. Groundwater wells were installed by water jetting methods to the top of permafrost. Observations of groundwater levels were made at intervals of about one week during the thawing seasons. Observations of vertical movement of runway pavements, building floors, and building footings were made at intervals of about two months. Probings were made at established points to determine frost levels at 2-month intervals during the thawing seasons.

9. RESULTS OF OBSERVATIONS. Where permafrost was present, seasonal thawing was observed to a depth of 10 ft adjacent to the runway. During the first 3 years after construction of the 160- by 210-ft hangar, thawing of the subsoil took place to a depth of 25 ft. Observed thawing under other smaller buildings placed on spread footings or concrete slabs directly on the ground ranged to a depth of 18 ft. The least thawing was observed under buildings having an air space between the floor and the ground. The least vertical movement occurred in structures supported on sand and gravel fills and on piling embedded in permafrost.

Eielson Air Force Base, Alaska

10. GENERAL. In connection with the construction of the runway extension at Eielson Air Force Base by the District Engineer, Alaska District assistance was obtained in drilling five ground temperature holes on a line crossing the runway. Thermocouple equipment for measuring ground temperatures in these holes was fabricated and installed by this office. Observations have been made for only a short time and are therefore not reported herein.

Ladd Air Force Base, Alaska

11. GENERAL. A 500-man barracks building being constructed at Ladd Air Force Base by the District Engineer, Alaska District is to be observed to determine the effect of

the structure on permafrost. Ground temperature holes have been drilled at several points under the building Thermocouple equipment for measuring ground temperatures has been constructed and will be installed by the St. Paul District Office when construction of the building is sufficiently advanced.

III Construction Operations

12. CONSTRUCTION SEASON. It has been found that the best season for construction operations in Alaska and western Canada is approximately the period from 1 May to 1 October, while in northeastern Canada it is approximately the period from 1 June to 15 October. Outdoor construction operations should be restricted to the best or warm season, but if it is necessary to work during the winter, outdoor construction operations should only be conducted when the temperature is warmer than -30° F. During a large part of the warm season, there is much daylight and little darkness, thus construction operations can be readily prosecuted on a two shift basis to increase total production to compensate in part for the short construction season. When cuts are to be made in frozen, fine-grained soils of high moisture content, as for borrow pits and landing strips, vegetation should be removed from areas only as large as the available earth-moving equipment can work in and readily remove the soil as it thaws. If too large an area is stripped of vegetation, the ground thaws deeply and becomes a bog in which the equipment cannot be operated. In some instances, blasting methods have been successfully employed both in the winter and summer to break up the frozen, fine-grained soil so that it may be excavated by ordinary earth-moving equipment. The winter season is the best time to perform subsurface drilling operations if cored soil samples are required for foundation design purposes. Frozen cores provide accurate information on actual soil moisture and density conditions.

13. CONSTRUCTION EQUIPMENT. Data on equipment for construction in arctic and subarctic regions were collected by reviewing reports on construction in arctic and subarctic regions by such agencies as the Civil Aeronautics Administration, Public Roads Administration, Alaskan Department, reports of manufacturers of equipment, lubricants, etc., and others familiar with arctic construction. Persons familiar with arctic construction equipment and manufacturers of such equipment were interviewed and the problems of arctic construction discussed in detail. The information obtained was submitted as "Interim Report on Arctic Construction Equipment" dated 12 July 1945. From the above information, it was determined that the same construction equipment that is used in the United States is suitable for use in the Arctic and Subarctic. In general, a heavier type of equipment is considered to be the most satisfactory. Equipment for arctic use must be suitably winterized and special attachments and optional parts should be specified when ordering equipment. Some special equipment which is similar to that used in the warmer climates is very desirable for thawing operations in frozen ground. These items include small portable steam boilers of about 2-boiler horsepower, accessories for steam boilers such as steam points and steam hose, hydraulic plant consisting of diesel or electric motor-driven pumps and hydraulic monitor or giants, together with the attendant pipe and valves. Winter tractor-drawn freighting equipment, including heavy duty sleighs and Go-devils and trailer-mounted asphalt heaters, are also useful in arctic construction. The accessibility of a site and the time, especially in the terms of seasons available for construction, are important factors to be considered in the selection and assignment of construction equipment. Because of the isolation of many of the sites, it is very important that an adequate stock of repair parts for the equipment be readily available. It is also suggested that on any particular job, equipment be standardized insofar as possible to

provide for interchangeability of parts. It is understood that other Government agencies are making comprehensive field tests of construction equipment in arctic and subarctic regions. This phase of the permafrost investigation has therefore been discontinued.

IV Meteorological Data Study

14. GROUND TEMPERATURE INSTALLATIONS AT WEATHER STATIONS. In order to accumulate data concerning ground temperatures as related to varying climatic conditions, observation equipment has been installed at weather stations throughout the Territory of Alaska, as listed below:

Aniak	Fairbanks	Kotzebue	Summit
Barrow	Fort Yukon	McGrath	Tanana
Bettles	Galena	Nome	Unalakleet
Big Delta	Gulkana	Shungnak	Wales

A similar installation was originally contemplated at Point Hope. However, large boulders encountered made it impossible to drill the temperature hole in the ground with the drilling equipment which could be conveniently transported to the site. See Figure 2. For this reason, the site at Point Hope has been abandoned. The installations at Nome and Fairbanks were made in September and November 1945, respectively. Installations at the other weather stations were made in two phases by personnel from the Permafrost Field Office at Ladd Air Force Base. Drilling and the installation of 2-in. pipe to a depth of 22.5 ft was accomplished during the period from 20 June to 25 August 1946. The pipe was installed in place, capped and protected by a timber frame pending installation of the thermohms. Installation of temperature observation equipment was accomplished during the period from 15 October 1946 to 12 January 1947. Resistance thermometer units were assembled by the St. Paul District Office and shipped to the field office at Ladd Air Force Base for installation. Details of the installations are shown in Plate 3. The U. S. Weather Bureau has assumed responsibility for making observations and recording data at all stations including Civil Aeronautics Administration stations. To date, sufficient data concerning ground temperatures are not available for analytical purposes. To increase the scope of this coverage, additional ground temperature installations are contemplated at outlying Alaskan and Canadian weather stations. Table 1 summarizes meteorological data obtained at the weather stations.

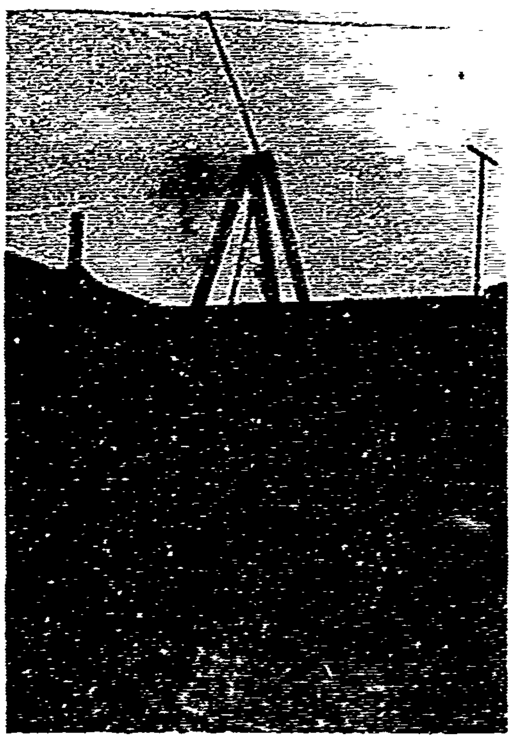


Figure 2. Portable churn drill rig developed for use in drilling temperature holes at weather stations. September 1946

TABLE 1

METEOROLOGICAL DATA AT WEATHER STATIONS

Weather Station (Observer)	Location Latitude Longitude	Elev. in Ft. M.S.L.	Years of Record	Temperatures °F: Mean Annual	Temperatures °F: Max.(+) Date	Temperatures °F: Min(-) Date	Average Annual Precipitation Inches: Total	Average Annual Precipitation Inches: Snow	Winds - Direction & Velocity - m.p.h.: Prevailing Direction	Winds: Max. Vel. Date	Winds: Avg. Vel.
SOUTHERN VALLEYS											
Aniak (U.S.A.O)	61°40'N 159°42'W	81	7	28.5	+84 6-22-43	-62 1-9-47	20.30	62.0	NNW	N.R.	N.R.
Gulkana (U.S.A.O)	62°09'N 145°28'W	1573	9	27.9	89 7-18-19	65 2-3-47	12.37	52.1	SSE	N.R.	N.R.
McGrath (U.S.A.O)	62°58'N 155°37'W	334	9	25.4	85 7-21-47	-64 2-3-47	19.93	103.3	NW	43 10-20-46	N.R.
BERING SEA											
Nome (U.S.W.B)	62°30'N 165°24'W	13	41	25.7	84 7-8-36	-47 1-15-19	19.84	63.6	NE	66 1-9-47	9.8
(1) Unalakleet (U.S.A.O)	63°54'N 160°42'W	14	4	26.0	79 7-8-46	-47 1-20-47	8.39	29.8	ENE	N.R.	N.R.
Wales (U.S.W.B)	65°37'N 168°03'W	9	2	19.6	75 7-5-26	-41 2-4-47	9.85	25.1	NE	N.R.	N.R.
YUKON VALLEY											
Bettles (U.S.A.O)	66°54'N 151°51'W	846	3	22.1	83 7-12-46	-55 1-17-47	15.23	88.5	NNW	N.R.	N.R.
Big Delta (U.S.A.O)	64°00'N 145°44'W	1268	8	27.9	90 5-28-47	-63 1-30-47	9.55	26.8	(3)	N.R.	N.R.
Fairbanks (U.S.W.B)	62°50'N 147°48'W	436	43	26.1	99 7-28-19	-67 1-22-16	11.49	59.3	NE	46 10-30-46	5.0
Fort Yukon (U.S.A)	66°35'N 145°18'W	419	30	20.2	92 7-16-18	-68 2-4-47	7.09	46.4	NNW		
(2) Galena (U.S.A)	64°43'N 156°54'W	120	2	23.4	85 7-21-47	-59 2-4-47	13.15	49.3	(4)	N.R.	N.R.
Northway (U.S.A.B)	62°58'N 141°56'W	1713	5	23.7	88 5-28-47	-70 2-3-47	12.51	30.7	NW	45 10-30-46	4.8
Summit (U.S.A.O)	63°20'N 149°09'W	2401	7	25.5	78 7-19-47	-45 2-5-47	21.40	140.3	NE	N.R.	N.R.
Tanana (U.S.A.O)	65°10'N 152°06'W	232	43	23.5	89 6-26-15	-71 1-15-47	13.59	43.2	E	N.R.	N.R.
ARCTIC DRAINAGE											
Barrow (U.S.W.B)	71°18'N 156°47'W	22	32	10.2	75 7-10-21	-56 2-3-24	4.18	22.5	NE	54 3-30-35	11.7
Kotzebue (U.S.W.B)	66°52'N 162°38'W	10	21	19.4	79 7-22-47	-58 3-16-30	7.71	26.6	E	52 3-30-35	11.5
Shungnak (U.S.A.O)	66°54'N 157°02'W	140	7	21.4	90 6-25-16	-58 2-5-47	17.70	61.5	E	N.R.	N.R.

Note: U.S.A.O.= U.S. Airway Observer; U.S.A. = U. S. Army; U.S.W.B. = U.S. Weather Bureau N.R. = No Record
(1) Temperatures for 1946-47, precipitation and snowfall for 1947
(2) Temperatures for 1945-46 & 47, precipitation and snowfall for 1947
(3) Winds erratic
(4) Insufficient records

V Thermal Properties of Soils and Insulating Materials

15. GENERAL. A laboratory investigation for the determination of thermal properties of typical soils and insulating materials under varying conditions of temperature, moisture, density, and composition was made by the University of Minnesota, under Contract No. W-21-018-eng-341. The tests required included thermal conductivity and specific heat as well as standard tests for moisture, density, and classification. Under the contract with the Corps of Engineers, the Engineering Experiment Station of the University of Minnesota began the study of thermal properties of soil in the fall of 1945. The investigation has been completed and a final report has been submitted to the Office, Chief of Engineers for review. Brief summaries of the soils and materials tested and the general character of results obtained are contained in the following paragraphs. Detailed descriptions of the materials, equipment, and test results are contained in the final report by the University of Minnesota entitled "Final Report, Laboratory Research for the Determination of the Thermal Properties of Soils", September 1948. See Figure 3, page 14.

16. THERMAL CONDUCTIVITY TESTS OF SOILS. Nineteen soils and rock types were tested for thermal conductivity under various conditions of moisture, density, gradation, particle shape, and temperature. These materials include one gravel and six sandy soils, six fine textured silt or clay soils, five minerals or rock types, and a peat soil. With the exception of a sand from South Lowell, Massachusetts, all of the soils were obtained from Alaska. The minerals and rocks were obtained in Minnesota, South Dakota, and Wisconsin. The tests have shown that the coefficient of thermal conductivity varies as follows:

a. Above freezing, it increases slightly with an increase in mean temperature.

b. Below freezing, for soils at low moisture contents, it shows very little change; for greater moisture contents, it shows an increase for a decrease in temperature.

c. For a change from unfrozen to frozen soil, it changes variably according to the moisture content. For dry soils it does not change; for soils of low moisture content, it decreases; and for soils of high moisture content, it increases.

d. At a constant moisture content, it increases with an increase in dry density. The rate of increase is about the same at all moisture contents and is not markedly different for frozen and unfrozen soils.

e. At a constant dry density, it increases with an increase in moisture content.

f. For saturated unfrozen soils, it decreases with a decrease in density. For saturated, frozen soils, the data indicate no well-defined relationship between density and conductivity.

g. It varies in general with the texture of the soil, being high for gravels and sands, lower for the sandy loams, and lowest for the silt and clay soils.

h. It differs appreciably for different soil minerals. Quartz has greater conductivity than plagioclase feldspar and pyroxene.

i. Angular soil particles have from 20 to 50 percent greater conductivity than rounded soil particles.

17. PREDICTION OF THERMAL PROPERTIES OF SOILS. From the results of the thermal conductivity tests, four charts were developed (Plates 4 to 7, inclusive) to aid in the prediction of conductivity values for other soils. Two of the charts are for sands or sandy soils and two are for silt or clay soils. Data for frozen materials are shown on one chart and data for unfrozen materials are shown on the second chart for each type of soil. Since the specific heat values for given temperatures were found to be quite similar for all soils tested, it appears to be reasonable to assume the same values for other soils. Average values of specific heat of dry soils were found to be 0.19 at 140° and 0.16 at 0° F and variations were in direct proportion to the temperature. The specific heat of wet soils may be calculated by the equation:

$$\text{Specific heat} = \frac{100 \times \text{sp heat of soil} + \text{moisture content}}{100 + \text{moisture content}}$$

The diffusivity of a soil may be computed if its coefficient of thermal conductivity, specific heat, and density are known. The equation for this computation is:

$$\text{Diffusivity} = \frac{\text{Thermal conductivity}}{\text{Specific heat} \times \text{density}}$$

18. THERMAL CONDUCTIVITY OF LIGHTWEIGHT CONCRETES. Test specimens of cell concrete and zonolite concrete were obtained during construction of the Fairbanks Research Area near Fairbanks, Alaska. The apparatus used in the tests of thermal conductivity of these concrete materials consists essentially of two flat plates heated uniformly by a heat source between them. Two slabs of the material to be tested are placed against these plates, and then two other flat plates whose temperatures can be controlled are placed against the outer sides of the slabs. The power used by the heating element and the temperature difference between the hot and cold plates were measured, and the coefficient of thermal conductivity was calculated. The material was tested dry. The data obtained are given in the final report by the University of Minnesota. Tables 2 and 3 give the order of magnitude of the conductivities:

TABLE 2

THERMAL CONDUCTIVITY OF ZONOLITE CONCRETE SLABS

Mix by Volume Cement:Zonolite	Density lb/cu ft	Low Mean Temperature	k*	High Mean Temperature	k*
1:4	33.6	-0.1° F	1.051	72.3° F	1.091
1:6	29.6	0.2° F	0.998	75.3° F	1.058
1:8	28.6	15.1° F	0.941	75.3° F	1.001
1:10	20.4	0.1° F	0.635	70.0° F	0.684

* k = thermal conductivity in Btu per sq ft per hr per °F per in.

TABLE 3

THERMAL CONDUCTIVITY OF CELL CONCRETE SLABS

Approximate Specific Gravity	Density lb/cu ft	k*
1.2	86.0	4.11
1.0	80.5	3.87
0.8	71.5	3.09

* k = thermal conductivity in Btu per sq ft per hr per ^{o}F per in.

It was found that the thermal conductivity increased with an increase in dry density and with an increase in mean temperature. Conductivities may be interpolated or extrapolated reasonably from the preceding values for dry materials. However, moisture must increase the conductivity of these materials significantly. Use of these materials in field construction for insulation has been ineffective. High groundwater keeps the insulation wet most of the time in the field test area.

VI Supplementary Studies

19. AERIAL PHOTOGRAPHIC RECONNAISSANCE. The Engineering Experiment Station of Purdue University, under Contract No. W-21-018-eng-336, and under the direction of the St. Paul District, Corps of Engineers made field investigations in Alaska during the summers of 1945, 1946, 1947, and 1948 for the purpose of developing a technique for predicting permafrost conditions and soil characteristics from aerial photographs. The investigation in 1945 was of a preliminary nature with the primary purpose of determining the feasibility of the project. As the investigation in 1945 produced favorable results, it was continued in 1946, 1947, and 1948. In 1945 the work was confined to the Tanana, Yukon and Koyukuk River Valleys and the coastal plain in the vicinity of Nome. Areas studied in detail were at Northway, Tanacross, Big Delta, Galena and Nome. In 1946 areas studied during the previous year were re-examined and, in addition, areas at Fairbanks and on the Seward Peninsula were investigated. In 1947, studies were made between Talkeetna and Peters Creek and between Curry and Houston along the Alaska Railroad, along the Richardson Highway between Copper Center and Big Delta, between Circle and Eagle Creek on the Steese Highway, Bettles, Fort Yukon, Umiat, Bethel, Barrow, and McGrath. In 1948, studies were made at Big Delta, Kotzebue, Elephant Point, Deering, Point Hope, Kobuk Valley, Noatak Valley, Shesualer, Noorvik, Kiana, Point Barrow, Admiralty Bay, Oumalik, Atkusuk, Ikpikpuk River Valley, Sagavanirktok Bluffs, Colville River Valley, coast between Point Barrow and Icy Cape, Barter Island, Beaver, Yukon, Gulkana, Chistochina, Slana, Tok, Northway, Tanacross, and Galena. Aerial photographs were furnished by the Army Air Forces. Where necessary photographs were not available, the areas were photographed by that organization prior to the time that ground studies were made by representatives of Purdue University. A report entitled "Summary and Statement of Technique, Aerial Photographic Reconnaissance Investigation, Frozen Soils in the Territory of Alaska," dated January 1948, revised in May 1948, is a summary of the techniques developed by Purdue University in its field investigations in Alaska from 1945 to 1947, inclusive. A manual on the interpretation of aerial photographs of terrain in arctic and subarctic regions for engineering purposes is being prepared by Purdue University for publication as a separate report in 1950. In a relatively undeveloped region such as the

Territory of Alaska, aerial photographs can be used to great advantage in locating the best sites for airports, highways, railroads, and military bases. When it is known that some type of engineering construction is to be done in a certain locality, aerial photographs of the locality are studied by an engineer familiar with the geologic and pedologic history and processes pertaining to the region. A general soil map of the locality can be developed from such a study in much less time and with much less field work than if the investigation were made by field reconnaissance.

20. GEOPHYSICAL EXPLORATION METHODS. Field studies of the feasibility of employing geophysical methods to determine the depth, areal extent, and stratigraphy of permafrost were made during September 1945 by Dr. J. H. Swartz of the Bureau of Mines and Mr. E. R. Shepard of the Office, Chief of Engineers. The work in 1945 was preliminary in character and the results were necessarily tentative in nature, requiring verification by further field work in undisturbed areas where the methods could be checked in detail by borings. During August of 1946, a field study was conducted in the Fairbanks Research Area and at Ladd Air Force Base, both near Fairbanks, Alaska, by Mr. E. R. Shepard. His study was concentrated upon locating waterbearing and other thawed strata within permafrost, as well as locating and outlining ice lenses in thawed ground and the depth of permafrost. Depth to the upper surface of the permafrost layer was not emphasized due to the relative ease with which this can be determined by probing. The following conclusions are contained in "Report on the Application of the Electrical Resistivity Method of Subsurface Exploration to Studies of Permafrost Problems in Alaska", by E. R. Shepard following his field study in 1946:

> "A careful analysis of two seasons' experimental studies of permafrost, by the electrical resistivity method of subsurface exploration at several locations in Alaska, has disclosed various anomalies and apparent conflicts which render definite or reliable interpretations impossible at all locations.
>
> "From the results of both seasons' studies, it is apparent that the top of shallow permafrost can usually be determined with satisfactory accuracy and that under some conditions the bottom of permafrost within moderate depths can also be determined. However, other factors than temperature appear to be present in some locations which may be mistaken for depth effects and thereby lead to erroneous interpretations.
>
> "From the limited data so far obtained, it appears that the method cannot be depended on to reveal the presence of waterbearing strata, ice crystals and lenses within permafrost, or even the presence of permafrost under all conditions.
>
> "Unknown factors which may be related to the chemical properties of the soil, not necessarily discernible in drill logs, appear to be more dominant in electrical resistivity data than are factors related to the thermal and mechanical properties of the soil.
>
> "While further investigations, which would necessitate considerable drilling and the making of temperature measurements for correlations, might resolve some of the outstanding uncertainties, it appears that the results so far obtained are not sufficiently encouraging to justify further efforts along this line at the present time."

It is believed desirable to determine the feasibility of using seismic methods to obtain the

surface elevation of deep permafrost, i.e., over 10 ft from the surface.

21. DEVELOPMENT OF TESTING EQUIPMENT. A portable churn drill rig was developed and constructed for use in isolated locations accessible only by air transport. This assembly, shown in Figure 2, is powered by two small gasoline motors and weighs approximately 2000 lb complete with all equipment. It has been used successfully in drilling ground temperature holes at certain weather stations throughout Alaska with the exception that it could not drill through boulders or very coarse gravel. Apparatus for measuring the thermal conductivity of soils has been developed by the University of Minnesota under its contract with the St. Paul District Office. See Figure 3. The design of this apparatus is essentially new, although certain principles were adapted which were used in the construction of the hot plate apparatus for thermal conductivity tests of insulating materials developed by the University of Minnesota and the apparatus used by the Bureau of Reclamation in testing concrete for thermal conductivity in connection with the Hoover (Boulder) Dam Studies. Complete details concerning this testing equipment are contained in the "Final Report, Laboratory Research for the Determination of the Thermal Properties of Soils", dated September 1948. The thermocouple wiring system which has been developed for field use in measuring ground temperatures is shown in Plate 8. A field test of various types of ground temperature measuring equipment and methods of installation was made at the Fairbanks Research Area. The results of this test, which are shown on Plate 9, indicate that the uninsulated temperature units which are placed directly in contact with the soil are more truly representative of ground temperatures.

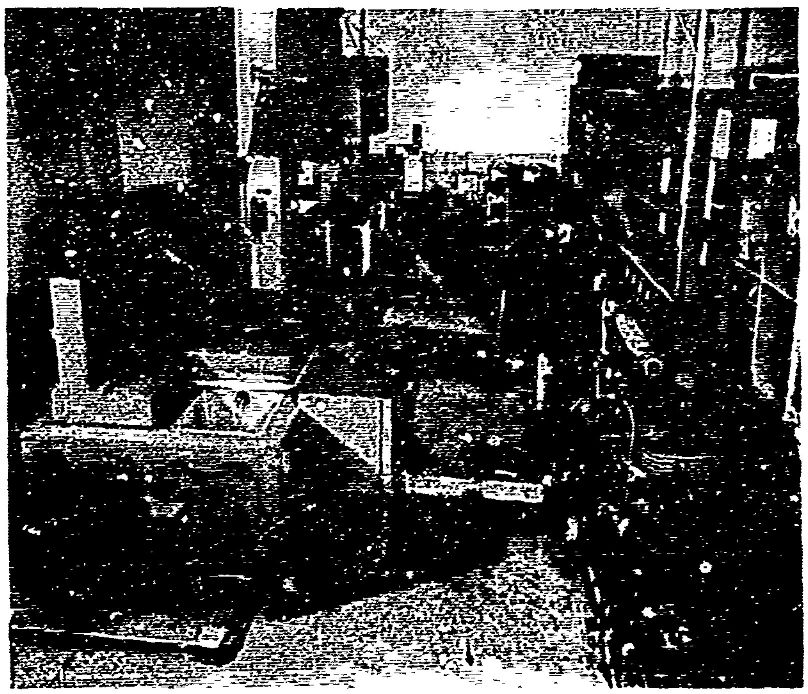


Figure 3. Soil thermal conductivity apparatus, June 1948

22. LIBRARY RESEARCH. During the course of the investigation, a large number of articles pertaining to permafrost and related problems and published in the English language have been examined. A bibliography of these articles, prepared by the Permafrost Division, St. Paul District Office is contained in Appendix II. In June 1947, contract agreements were completed with the Stefansson Library of New York, N. Y., whereby a search would be made of foreign literature (primarily Russian) pertaining to engineering construction on permanently frozen ground in arctic and subarctic regions, to summarize the contents thereof, and to furnish, upon request, complete English translations of selected articles. A tabulation of the various articles examined by the Stefansson Library is

contained in Appendix II. Bibliographies prepared by various agencies are also given in Appendix II. One of the best Russian publications examined was "General Permafrostology" by M. I. Sumgin, S. P. Kachurin, N. I. Tolstikhin and D. F. Tumel.

VII Design and Construction Studies at Fairbanks Research Area

23. PURPOSE. The Fairbanks Research Area was constructed for the purpose of providing an opportunity to observe various types of structures erected on permafrost under conditions that would be known and recorded from the beginning to the conclusion of operations.

24. GENERAL CONDITIONS. The Research Area is located about 2-1/2 miles northeast of Fairbanks, Alaska. See Plate 10 and Figure 4. The terrain on which it is built is characterized by a comparatively smooth gentle slope which generally provides good surface drainage. Geologically, the Research Area is located on the lower colluvial slopes between the valley fill and the upper colluvial slopes of the rock upland known as Birch Hill. The mean annual temperature at Fairbanks is about 26° F with extremes of +88° F and -58° F. The total annual precipitation is about 12 in., including the annual snowfall of about 4 ft. The natural soil underlying the Research Area to a depth of 50 ft is principally silt with some fine sand and occasional layers of peat. Typical data for weather and soil conditions are shown on Plate 11. Under natural conditions, permafrost is encountered at depths of 3 to 6 ft below the surface. The site of the investigation has been divided into three areas as shown on Plate 10 and in detail for each area on Plates 12, 13 and 14. The general plan is as follows:

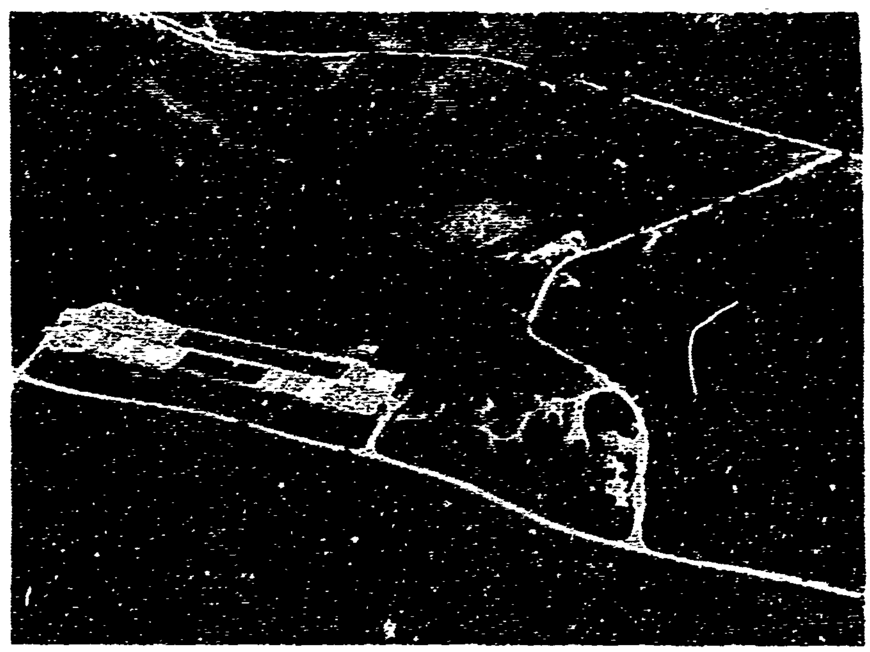


Figure 4. Field research at Fairbanks, general view. Area No. 1 at top center. Area No. 2 at left. Area No. 3 at lower center.

a. Area No. 1 -- ground and pavement surface studies. In this area, the effect of the climatic factors such as air temperature, solar radiation, wind velocity, humidity, cloudiness, and precipitation, on ground temperature, especially where permafrost is present, will be determined under various ground and pavement surface conditions. See Plate 12.

b. Area No. 2 -- runway foundation studies. The effect of the construction of runway sections with various pavement types, insulators and base courses on ground temperatures are being determined. See Plate 13 for the various combinations of fill, insulation and surfaces constructed and under observation.

c. Area No. 3 -- building foundation studies. Buildings have been constructed with various ground exposures and insulators to determine the effect of these types of foundation construction on ground temperatures, especially on the permafrost. Pile foundations have been studied to a limited extent from observation of several piles installed at various depths of embedment in the permafrost to determine whether the freezing and heaving of the active layer will displace the piles. See Plate 14.

25. INSTALLATION AND OBSERVATION OF TEST FACILITIES. Construction at the Fairbanks Research Area was begun in April 1946 by the Alaskan Department with inspection and supervision by Permafrost Field Office personnel of the St. Paul District Office. Core and churn drilling operations were begun in February 1946 and completed in June 1946. Continuous samples were taken from all core borings with nearly 100 percent recovery in the frozen silt. Installation of all special equipment, such as ground temperature observation equipment, was made by employees of the Permafrost Field Office. Clearing and stripping operations were begun in March and April 1946, respectively. General construction operations were completed in the fall of 1947 following changes in plans involving the construction of additional structures. Facilities are provided in each test area for the observation of ground temperatures, groundwater levels, vertical movement of ground surface, pavement surface, or structure, probing to ground frost level, and obtaining soil density samples. Observations of ground temperatures are presently being made at weekly intervals. Groundwater levels are also observed at two-week intervals during the open season. Vertical movements are observed at one-month intervals. Probings supplemented by auger borings are made at two-month intervals to check the ground frost levels. Test pits are excavated and soil density tests are made as required at critical places in the foundations. Climatic factors are being observed daily in the area.

VIII Analyses of Heat Transfer in Ground

26. PURPOSE. The purpose of the study of heat transfer made in connection with this investigation is to develop a method of computation, based on theory, experiments, and field observations, which will enable the engineer to determine, with reasonable accuracy, the depth of thaw in frozen ground under structures commonly built at airfields in arctic and subarctic regions.

27. SCOPE. Studies have been made of ground temperature conditions under airport runways, buildings, and access roads. Effects of moisture, density, and other physical properties of ground on heat transfer have been investigated. Consideration has been given to various types of insulation as well as open air spaces under structures. Ground temperature effects have been associated with their causes such as solar radiation and other climatic conditions.

28. REVIEW OF LITERATURE. A study of available published literature revealed very few references which might be used to calculate the depth of thaw of the ground. A

bibliography of literature pertinent to analyses of heat transfer in ground is included at the end of this report. The latent heat of fusion of ice complicates the mathematical problems involved. Equations exist for the temperature within a thick body having a plane surface and having a sinusoidal temperature variation on the surface[1,2*]. Generally, these equations are of small value, if any, when applied to soil which freezes and thaws. Standard physics books may be used for the commonly known equations of heat flow[3].

a. Russian literature. A translation from the Russian work of M. I. Sumgin and others[4] contains an equation for the depth of thaw:

$$x = h + \sqrt{\frac{2kv_h t}{l \frac{w}{100} d} - \frac{kv_1 t}{x_1 l \frac{w}{100} d}}$$

x = depth of thawing in meters
h = depth to plane of temperature v_h = .05 to .10 m
k = coefficient of thermal conductivity in cal per m per hr per sq m per °C
v_h = average temperature at depth h in °C
t = time of thaw in hr
l = latent heat of fusion of water = 79.7 cal per g
w = moisture content in percentage of dry weight of soil
d = dry weight of soil in kg per cu m
v_1 = average temperature of ground at a fixed small distance x_1 below the zero ground isotherm.

The preceding equation gives an approximate depth of thaw; however, it is difficult to determine certain factors such as h and v_h. In the same reference by Sumgin, an equation is given for the conditions necessary for the existence of permafrost:

$$k_f \, v_f \, t_f > k_u \, v_u \, t_u$$

f = factors during freezing
u = factors during thawing
k = coefficient of thermal conductivity
v = average temperature of the ground at depth h
t = time during freezing or thawing.

It is felt that this equation is a definite contribution and will be discussed later.

b. Scandinavian literature. One of the most outstanding publications reviewed was written by Gunnar Beskow[5] and some of the more applicable concepts presented are summarized here.

"The water supply to the freezing layers in frost heaving ground comes practically exclusively from capillary flow of water below." (p 3).

* Superior numbers refer to references in bibliography at end of this report.

"The critical grain size for frost-heaving soil is placed at 0.1 - 0.06 mm." (p 25). See Table 4.

TABLE 4

LIMITS BETWEEN FROST-HEAVING AND NON-FROST-HEAVING SOILS
(Table 11 from "Soil Freezing and Frost Heaving with Special Application to Roads and Railroads" by Gunnar Beskow)

Soil Group		Average Diameter mm	Amount Passing Sieve 0.062 mm	Amount Passing Sieve 0.125 mm	Capillarity K_F Meters	Hygroscopicity W_h
0. Non-frost-heaving under any circumstances	Sediment	0.1	<30%	<55%		-
	Moraine	-	<15%	<22%	< 1	-
1a. Causing frost-heave only at surface and for very high groundwater	Sediment	0.1-0.07	30-50%	-	1-(1-3/4)	
	Moraine	-				
1b. Same, except effects whole road base for very high groundwater	Sediment	0.08-0.05	15-25%	22-36%	(1-1/4)-(2-1/2)	-
	Moraine	-				
2. Normally frost-heaving and liable to frost boils for groundwater depths 1-1/2 m	Sediment	<0.05	>50%	-	2-20	<5 1-4
(moraine 1 m)	Moraine	-	>25%	>36%		
3. Frost-heaving clays but not liable to boils	(Sediment)	-	-	-	20-?	5-(10?)
4. Non-frost-heaving stiff clays	(Sediment)	-	-	-	?	(10?)

"Under natural conditions it can be said that heaving of ground caused by the expansion of the existing water, independent of any water supply is under all circumstances very small." (p 38)

"- - - -: Water movement across a fissure can only occur over points of direct contact." (p 92)

"The rate of frost heave in a fissured clay is for practical purposes inversely proportional to the groundwater depth." (p 195)

"To summarize, then, we can say that for coarse non-frost-heaving soils the temperature for freezing and thawing is practically the same, and is very slightly less than 0° C. For frost-heaving soils there is quite a difference between the frost line temperature during freezing and thawing; the receding frost line temperature is 0° C or very slightly less, while the frost line temperature during freezing is considerably lowered, being greater the

finer the soil is and the faster it freezes.

"Thus in a general way, heat flow in frozen soil occurs by a smoothing out of temperature differences between two constant temperature surfaces, the frost line and a constant temperature surface lower down representing the average yearly surface temperature, (about 10-20 meters deep) below which there is no temperature variation at any level." (p 116)

"The effect then of the ground surface temperature is that it determines the greatest possible frost depth." (p 117)

"The effect of vegetation is, as a rule, to lower the temperature, since it is a better insulator during the warm period of the year than during the cold." (p 123)

An equation for the depth of frost (p 134) is as follows:

$$x = \sqrt{\frac{2k_f v_o t}{P}}$$

x = depth of freeze in cm
t = time that surface temperature is below 0° C in hr
k_f = heat conductivity of frozen soil in cal per cm per sec per °C
v_o = average of surface temperature during freezing season in °C
P = "frost storing capacity"

$$P = 79.7 \frac{w}{100} d + \frac{v_o}{2} (0.45 \frac{w}{100} d - 0.55d) \text{ cal per cm}^3$$

$\frac{w}{100} d$ = weight of water per unit volume of soil

79.7 = latent heat of fusion of water in cal per g
0.45 = approximate specific heat of ice in cal per cm^3
d = dry density of the soil in g per cu cm
w = water content of the soil in percent of dry weight
0.55 = specific heat of soil.

The product $v_o t$ is called the "freezing resistance" and is determined by measuring the area under a time-temperature curve for the air by means of a planimeter. Complicating factors in determining the depth of frost are snow cover, heat radiation, heat conduction from below, freezing point of soil, etc. Each layer of soil parallel to a plane surface requires a definite number of degree-hours to freeze as given by the following equation (p 138):

$$F = v_o t = \frac{P_1}{k_f} \times \frac{b_1^2}{2} \text{ °C hr}$$

F = "freezing resistance" of layer 1
b_1 = thickness of layer in cm
P_1 = frost storing capacity in cal per cm^3.

Practical measures to avoid frost damage are discussed. It is stated that frost damage depends mainly on unevenness of heaving, different degrees of heaving at different parts of the structure, causing breakage and deflections.

"In most cases, a practical objective is to prevent heaving from reaching disastrous degrees of inequality. Sometimes, as in the case of most buildings, it is necessary to prevent all or nearly all movement, usually by excavation to 'frost-safe depth' and refilling with non-frost heaving material. But in the case of roads, runways and railways, a rather large amount of heaving may be tolerated, the crux being to avoid abruptness (both for sake of pavement and ease of traffic movement). Here one should aim at moderating and smoothening of heave action, e.g., through cutting off the peaks of the frost heave curve. It is not difficult to minimize frost action by excavation and filling when expense doesn't matter, but it takes expert judgment to select the simplest and cheapest way to reach the right reduction in frost heaving."

"- - - -, the main frost damage of roads is due to the softening of soil from melting ice lenses, causing a decrease of bearing strength in the soil. For silts, especially, the mechanical effect of this water excess may be tremendous ('frost boils'). This melting phenomena is not dealt with in this book; for roads without concrete pavement, it is the really disastrous consequence of frost action. Frost preventive measures practiced in Scandinavia are aimed principally to guard against this softening due to melting of the subgrade soil, thus, e.g., the depth of excavation and insulating backfill are dimensioned purely in order to insure that the bearing capacity is sufficient. In these cases, the backfill thus does function as a sub-base layer."

In the article "Scandinavian Soil Frost Research of the Past Decade", Proceedings of the 27th Annual Meeting of the Highway Research Board[6], Mr. Beskow again describes methods of computing frost depth from temperature conditions and material properties.

c. American literature. For the case discussed in his article "Prediction of Temperature-Distribution in Frozen Soils", Part III, Transactions of 1943, American Geophysical Union[7], Mr. W. P. Berggren develops the theory in a remarkable manner, but he points out that the Stefan equation

$$x = \sqrt{\frac{2k_f(32 - v_o)t}{L}}$$

is "almost an exact solution" when the latent heat of material is large compared to its heat capacity and when the temperature of the soil is equal to the freezing point.

x = depth of freeze
k_f = thermal conductivity of frozen soil
L = latent heat per cu ft
32 = freezing point of material in ^{o}F
v_o = fixed subfreezing surface temperature in ^{o}F
t = time in hr.

Mr. Berggren also points out that $(32 - v_o)t$ may be the integral of the temperature difference and time or the area swept by the curve. These statements parallel those of Beskow and support the theory as developed in this report. The Corps of Engineers' Frost Effects Laboratory has developed a graphical solution for Mr. W. P. Berggren's theory. This graphical solution is included in Report on Frost Investigation, 1944-1945, New England Division, Corps of Engineers, Plate 22[16]. In Addendum No. 1, 1945-1947, to Report on Frost Investigation 1944-1945[17], a comparison of predicted depths of frost penetration as computed by four equations and a design curve (Figure 2, Engineering Manual, Part XII, Chap. 4, March 1946), and observed depths of freezing at several airfields in the United States is presented. This comparison is shown on Table 5. Equation 83 includes the effect of latent heat while the other equations include the effect of latent heat and volumetric heat. Equation 83 is basically the same as the equation used by the St. Paul District to compute depth of thaw penetration in permafrost regions except that a correction factor has been added in the latter case to provide for the effect of surface characteristics. In addition, the total depth of thaw is computed by determining the degree-days of heat required to penetrate each layer of a multiple layered soil system. A more detailed discussion of the equation used by the St. Paul District is included in subsequent paragraphs of this report.

29. SOURCES OF HEAT ENERGY. The surface of the earth receives energy from the sun and from the center of the earth. The radiant energy which reaches the outer atmosphere of the earth is approximately 1.92 g cal per min per sq cm of area normal to the incident ray[8]. The amount of heat transmitted from the center of the earth is infinitesimal compared to that received from the sun. As an example, he temperature gradient in a deep well at Umiat, Alaska is approximately 1° F per 58 ft. See Plate 15. Of the radiant energy which reaches the outer atmosphere of the earth, not all reaches the surface; clouds, dust, vapor, vegetation, and local obstructions are some of the factors which interfere. The inclination of the earth's axis to the plane of revolution gives seasonal variation in the length of time the sun shines per day and in the angle of incidence of the sun's rays. In addition, the topography of the surface of the earth affects the angle of incidence. It is for this reason that southern slopes are warmer than others on the average. Though it is not possible to compute theoretically the amount of solar radiation, direct and indirect, which reaches a given area, it is possible to measure it with a pyrheliometer. During the years 1936-1947, inclusive, the solar radiation received annually at Fairbanks, Alaska averaged 82,150 g cal per sq cm or 302,887 Btu's per sq ft.[9] Plate 16 shows the amount of radiation received during the years of record. Not all the radiant energy which reaches the surface of the earth from the sun is absorbed. The earth's surface radiates heat into outer space, and the amount of radiation is a function of the temperature, color, nature of the material, and the area exposed. The radiant energy from the earth has a much lower frequency than solar radiation and does not pass through the atmosphere as readily. This effect is known as the "greenhouse effect", i.e., the radiation received is greater than the radiation given off which results in an increase in ground surface temperature. Data concerning outgoing radiation are not available to the extent that data concerning incoming radiation are, but one estimate for Alaska is 0.40 g cal per min per sq cm or 1.475 Btu's per sq ft as a maximum.

30. LOCATION. The depth of thaw is dependent upon such location factors as latitude, altitude, direction of exposure to sun, shading or decrease in radiation, reflection or intensification of radiation, proximity to large bodies of water, and proximity to local sources of heat.

31. SURFACE TEMPERATURE. Surface temperature is one of the factors in the equation for depth of thaw. It is dependent upon the solar radiation received and emitted heat lost to the air by conduction and convection, heat lost or gained due to evaporation or condensation of surface moisture, thermal diffusivity of the soil below the surface, and heat transferred from the interior of the earth. Surface temperature data are not commonly available for most areas. However, air temperatures which are observed at all weather stations are related to surface temperatures. Normally, the surface of the earth heats the air so the surface is warmer than the air. Observations of air and concrete surface temperatures by the Minnesota Highway Department during January and June 1941 are shown in Plates 17 and 18, respectively. It may be noted that during periods of sunshine (high solar radiation), the surface temperature was much higher than the air temperature. During cloudy periods the air and surface temperatures approached each other more closely. A graph of average monthly temperatures (Plate 19) shows the general relationship between air and concrete surface temperatures. Snow cover affects both air temperature and surface temperature, because of its ability to reflect solar radiation, its low conductivity, and its latent heat. It is thought that snow cover need not be considered a depth of thaw problem in airport maintenance, since roads and runways generally are kept clear of snow. Vegetation affects air and surface temperatures because of shading and transpiration. The quantitative effect defies analysis, but the qualitative effect of vegetation is to lower the mean annual temperature of the surface and to conserve permafrost. Vegetation may be very important when it is the purpose of the engineer to maintain permafrost.

32. DEVELOPMENT OF EQUATIONS. The basic concept used in the development of the equation for depth of thaw used in this report is the well-known electrical equation:

$$I = \frac{E}{R} \tag{1}$$

I = current in amperes, or coulombs per sec
E = difference of potential in volts
R = resistance in ohms.

which is similar to the heat equation:

$$Q = \frac{T}{R} \tag{2}$$

Q = quantity of heat in Btu per hr
T = temperature difference between surfaces in °F

$R = \frac{b}{k}$ = thermal resistance in °F per Btu per sq ft per hr

b = average thickness of a layer in ft
k = thermal conductivity in Btu per hr per °F per sq ft per ft of thickness.

Note: In the thermal conductivity studies described in Chapter V and the summary plots, Plates 4 to 7, inclusive, k is expressed in Btu per sq ft per hr per unit thermal gradient in °F per in. To make these values dimensionally homogeneous for use in heat transfer studies, they must be divided by 12, thus converting to the units stated above.

The following equation is the standard heat equation:

Site	Test Area	Year	Mean Annual Air Temp. °F (V_a)	Freezing Index °F Days (F)	Freezing Index Duration Days (t)	PAVEMENT (1) Type	PAVEMENT Thick in Inches	BASE (11) (111) Class.	BASE Thick in Inches	BASE Water Content % (w)	BASE Density lbs/ft³ (γ)	SUBGRADE (11) (111) Class.	SUBGRADE Thick in Inches	SUBGRADE Water Content % (w)	SUBGRADE Density lbs/ft³ (γ)
DOW	I AND III	1943-1944	42.5	1515	108	B.C.	4.0	GW	17	9.9	135	CL	-	38.5	81
	II			1690	123	B.C.	3.5	GW	36	4.2*	135*	CL	-	19.3*	107*
	IV TO VII			1745	130	P.C.C.	7.0	GW	15	9.2	133	[CL	38	28.4	92
												SC]	-	23.4(ϕ)	98(ϕ)]
	A	1944-1945		1445	104	P.C.C.	7.0	GW	15	11.1	119	[CL	42	[25.7	98
												SC]	-	25.4 NP]	105 NP]
	B			1445	104	B.C.	3.5	GW	31	6.9	131	CL	-	[31.1	95
														24.2 NP]	92 NP]
	C			1345	88	B.C.	3.5	GW	42	9.2	121	CL	-	19.3	109
	C			1445	104	B.C.	3.5	GW	42	9.2	121	CL	-	19.3	109
	TURF			1445	104	T.S.	6.0	-	-	-	-	CL	-	[23.4	99
														15.2 NP]	112 NP]
	D	1945-1946		1420	99	B.C.	3.5	GW	40	13.5*	128*	CL	-	17.7*	115*
	E			1420	99	B.C.	3.5	GW	36	10.1*	136*	CL	-	22.4*	101*
	E			1090	75	B.C.	3.5	GW	36	10.1*	136*	CL	-	22.4*	101*
	F			1060	74	P.C.C.	7.0	GW	20	8.1*	130*	CL	-	22.5*	110*
	TURF			1420	99	T.S.	6.0	-	-	-	-	CL	-	22.4(ϕ)	101(ϕ)
PRESQUE ISLE	A	1944-1945	39.0	2050	115	P.C.C.	7.0	GW	33	6.3	134	SC	-	[17.9	108
														16.2 NP]	113 NP]
	B			2080	115	B.C.	4.0	[C.R.	4	-	-	GM	-	[14.8	114
								GW]	30	6.5	134]			14.2 NP]	114 NP]
	TURF			140	25	T.S.	5.0	-	-	-	-	SC	-	[18.6	103
														15.9 NP]	110 NP]
	A	1945-1946		2240	126	P.C.C.	7.0	GW	32	10.4*	133*	GC	-	17.0*	117*
	C			2250	120	B.C.	3.5	[C.R.	35	-	-	GC	-	13.6*	115*
								GW]	26	6.3*	*132]				
	D			2250	124	B.C.	3.5	[C.R.	35	-	-	GC	-	18.4**	120**
								GW]	25	10.5**	**142]				
	TURF			2240	128	T.S.	5.0	-	-	-	-	GC	-	13.6(ϕ)	115(ϕ)
BEDFORD	A	1945-1946	46.5	385	99	P.C.C.	6.0	GW	18	4.8*	119*	SW	-	5.3*	109*
	B			695	87	B.C.	5.0	GW	14	4.8(ϕ)	119(ϕ)	SW	-	5.3(ϕ)	109(ϕ)
	B			345	41	B.C.	5.0	GW	14	4.8(ϕ)	119(ϕ)	SW	-	5.3(ϕ)	109(ϕ)
OTIS	A	1944-1945	48.7	300	60	B.C.	6.0	-	-	-	-	[SP or	53	9.5**	**124
												ML		23.5**	** 87
												SP	24	1.2	119
												GP]	-	0.8	126]
HOULTON	A	1944-1945	40.5	1605	107	B.C.	1.5	S.CRM.	6	14.3	113	[GP	30	14.7	118
												GC]	-	[8.3	134]
														10.1 NP]	NP 116]
TRUAX	A	1944-1945	46.0	1210	88	B.C.	2.5	[C.R.	8	-	-	[CL	25	21.1*	108*
								GP]	15	5.3*	*141]	SP	36	6.1*	115*
												CL]	-	21.1*	108*]
	B			1245	95	B.C.	2.5	[C.R.	18	-	-	CL	-	27.0	99
								GP]	25	7.7	122]				
	-			1245	97	P.C.C.	6.0	GP	48	12.7	112	CL	-	30.0	82
	A	1945-1946		1020	93	B.C.	2.5	[C.R.	8	-	-	[CL	26	27.5*	95
								GP]	18	6.0*	*140]	SP	36	19.6*	118*
												CL]	-	27.5*	95*]
	C			1060	100	P.C.C.	7.0	GP	30	10.1*	*129	[CL	32	35.5*	87*
												SP]	-	20.4*	113*]
	D			1055	99	B.C.	2.5	[C.R.	20	-	-	CL	-	25.9*	93*
								GP]	30	5.6*	*139]				
SELFRIDGE	B	1945-1946	47.6	645	61	P.C.C.	10.0	GP	12	11.5	99	[ML	15	17.0	112
												SP	30	22.3*	100*
												CL]	-	36.2*	85(ϕ)]
PIERRE	A	1944-1945	47.5	760	104	P.C.C.	7.0	GP	7	8.7*	135*	[CL	32	15.1*	105*
												CH]	-	25.5*	90*]
	B			695	71	B.C.	5.5	GP	9	6.4*	140*	CL	-	14.1*	97*
	TURF			660	69	T.S.	4.0(1)	-	-	-	-	[CL	40	12.1*	98*
												CH]	-	18.7*	90*]
	A	1945-1946		1025	99	P.C.C.	7.0	[GP	7	7.4*	*142	[CL	27	21.6*	97*
								CL]	8	15.9*	*110]	CH]	-	21.7**	97**]
	C			1025	99	B.C.	6.0	[GP	8	6.7*	*126	CL	-	12.7*	92*
								CL]	7	13.6*	*115]				
SIOUX FALLS	A	1944-1945	46.2	915	76	B.C.	2.0	[GC	10	7.0*	*132	[CL or	-	23.8*	95*
								CL]	12	16.7*	*112]	CH]		30.9*	86*]
	A	1945-1946		1220	82	B.C.	2.0	[GC	10	7.1*	*137	[CL or CH	48	29.0*	89*
								CL]	12	21.4*	*103]	SP-CL]	-	15.9*	97*]
	B			1310	100	P.C.C.	6.0	-	-	-	-	[CH	90	33.0*	85*
												CL	11	27.5**	87**
												SC]	-	15.9(ϕ)	97(ϕ)]
WATERTOWN	A	1944-1945	42.5	860	62	P.C.C.	8.0	-	-	-	-	[SP-OL	32	14.6*	112*
												OL-CL	20	23.8*	87*
												GP]	-	3.8*	120(ϕ)]
	B			840	59	B.C.	5.0	GP	8	4.9*	139*	[SP-OL	22	14.1*	103*
												OL-CL	11	22.1*	80*
												GP]	-	4.4*	120(ϕ)]
	TURF			880	64	T.S.	8.0	-	-	-	-	[SP-OL	52	6.4*	136*
												GP]	-	4.4*	120(ϕ)]
	A	1945-1946		1715	98	P.C.C.	9.0	-	-	-	-	[SP-OL	24	14.6(ϕ)	112(ϕ)
												OL-CL	22	23.8(ϕ)	87(ϕ)
												GP]	-	3.8(ϕ)	120(ϕ)]
	B			1715	98	B.C.	5.0	GP	12	4.9(ϕ)	139(ϕ)	[SP-OL	30	14.1(ϕ)	103(ϕ)
												GP]	-	4.4(ϕ)	120(ϕ)]
FARGO	A	1944-1945	39.2	1395	79	B.C.	1.5	[S.CRM.	0.5	11.1*	*122	[OH-CH	8	26.7*	92*
								CL-SP]	14	10.6*	*126]	CH]	-	31.1*	86*]
	A	1945-1946		2465	125	B.C.	1.5	[S.CRM.	6.5	11.1(ϕ)	122(ϕ)	[OH-CH	12	26.7(ϕ)	92(ϕ)
								CL-SP]	11	10.6(ϕ)	126(ϕ)]	CH]	-	31.1(ϕ)	86(ϕ)]
GREAT BEND	A	1944-1945	55.0	50	5	P.C.C.	7.0	SM or SP	6	2.0*	120*	[SP-CL	35	15.1*	109*
												or CL-SP		15.1*	108*
												CL]		17.0*	100*
	A	1945-1946		130	11	P.C.C.	7.0	SP	5	2.0(ϕ)	120(ϕ)	[SP-CL	35	15.1(ϕ)	109(ϕ)
												or CL-SP		13.1(ϕ)	108(ϕ)
												CL]	-	17.0(ϕ)	100(ϕ)]
BISMARCK	A	1944-1945	39.0	1850	85	B.C.	4.5	SC	6	4.7*	130*	[CL-ML	49	16.8*	97*
												SP]	-	8.1*	99*]
CASPER	A	1944-1945	47.4	355	59	P.C.C.	7.0	-	-	-	-	[SP-CL	29	11.4*	112*
												SP	12	6.8*	120*
												SP]	-	5.3*	111*]
	B			355	54	B.C.	5.0	GW	7	3.8*	131*	[SP-CL	12	6.2*	117*
												SP	32	3.5	109*
												SP-CL]	-	6.2*	117*]
FAIRMONT	A	1944-1945	52.0	380	70	P.C.C.	8.0	-	-	-	-	[CL	25	28.0*	89*
												CH]	-	23.0*	88*]
GARDEN CITY	A	1944-1945	55.0	25	7	B.C.	1.5	SC	10	5.0*	128*	[CL	36	15.9*	107*
												CH	-	19.1*	95*
												or CH-CL]		16.3*	97*]

Avg. Vol. Heat Btu/(Ft.³x°F) (C)	Avg. Latent Heat, Btu/Ft³ (L)	(IV) Observed Depth of Freezing in Inches	Predicted Depth of Freezing in Inches (III) Eq. 83	Eq. 93	Eq. 154	Eq. 154 Flex Pave.	Eq. 158	Design Curve
37.6	[illegible]	[illegible]	63	62	53 ◄	► 48 ◄		55 ◄
[illegible]	1300	[illegible]	100	87	26	26		► 27
42.8	3900	43	65	95	41	► 48 ◄		98
44.1	3035	54	65	58 ◄	41	48 ◄		► 53 ◄
39.2	2510	52	75	66	47 ◄	50 ◄		► 53 ◄
40.0	2060	60	79	► 67	47	50		51
40.0	1995	62	81	► 69	49	52		53
39.0	3500	74					57	
42.1	2530	50	72	62	44 ◄	► 47 ◄		► 55 ◄
41.5	2205	48	76	66	► 47 ◄	50 ◄		53 ◄
41.6	2110	44	68	99	42 ◄	► 43 ◄		47 ◄
44.6	2780	54	99 ◄	► 52 ◄	37	44		46
42.0	2210	26					57	
38.7	1985	70	96	85	58	► 67 ◄		65
37.4	1870	72	99	87	62	► 70 ◄		65
39.1	2790	13					12 ◄	
41.1	2450	78	91	► 80 ◄	57	64		65
37.0	1795	68	106	92	► 65 ◄	72 ◄		► 65 ◄
44.0	2740	69	85	76	54	61		► 65 ◄
37.5	2290	50					► 56 ◄	
24.0	860	40	96	76	54	60		► 41 ◄
26.0	805	26	88	70	49	54		► 33
26.0	865	26	62	49	35	40		► 27 ◄
27.4	1485	35	56	51 ◄	42 ◄	46 ◄		► 35 ◄
36.0	2160	49	81	72	► 51 ◄	52 ◄		56
39.9	2505	48	68	58	41	51 ◄		► 43 ◄
43.9	1865	56	78	64	45	65		► 50 ◄
38.8	2070	55	74	62	44	► 50 ◄		► 50 ◄
43.7	2430	46	62	53	37	► 47 ◄		► 45 ◄
43.9	2550	48	61	53 ◄	37	44 ◄		► 46 ◄
43.2	1560	59	78	► 65 ◄	44	66		46
44.6	2880	35	90	43	30 ◄	40 ◄		► 36 ◄
37.9	2150	43	65	54	39 ◄	46 ◄		► 44 ◄
32.9	1440	25	62	52	► 37	42		38
33.6	1680	6					34	
39.1	2685	48	89	52 ◄	37	44 ◄		► 45 ◄
30.0	1670	44	74	63	► 45 ◄	51		► 45 ◄
40.5	1825	40	56	49	35 ◄	► 37 ◄		► 43 ◄
36.5	3020	47	60	55 ◄	38	40		► 49 ◄
38.9	3960	42	54	50	35	► 41 ◄		51
36.7	2525	38	58	52	► 37 ◄	45		42 ◄
29.9	1976	42	62	55	39 ◄	44 ◄		► 41 ◄
30.6	1240	42					43 ◄	
29.7	2010	75 TH	88	► 77 ◄	55	64		58
29.6	1330	79 TH	108	90	64	► 69		58
43.2	2985	46	65	59	42 ◄	► 43 ◄		52 ◄
42.3	3395	72 TH	81	► 73 ◄	52	53		69 ◄
36.4	525	13	37	19 ◄	► 13 ◄	20		11 ◄
36.2	1600	24 TH	27 ◄	21 ◄	15	► 22 ◄		17
28.7	1905	46	73	70	► 50 ◄	54		► 50 ◄
29.2	1050	30	42	36 ◄	25 ◄	► 33 ◄		► 27 ◄
29.7	870	19	61	47	34	39		► 27
38.1	3550	25	31	28	► 20 ◄	28		20
36.2	990	12	15 ◄	► 11 ◄	8 ◄	9 ◄		8 ◄

EQUATIONS:

83 $x = \sqrt{\frac{48\,k\,F}{L}}$

93 $x = \sqrt{\frac{48\,k\,F}{L+C\left(v_o-32+\frac{F}{2t}\right)}}$

154 $x = \sqrt{\frac{24\,k\,F}{L+C\left(v_o-32+\frac{F}{2t}\right)}}$

158 $x = -\frac{d}{k}+\sqrt{\left(\frac{d}{k}\right)^2+\frac{24\,k\,F}{L+C\left(v_o-32+\frac{F}{2t}\right)}}$

DESIGN CURVE - Fig. 2, E.M. Part XII, CHAPT. 4, MARCH 1946

x – Depth of Frost Penetration in Feet.
k – Thermal Conductivity in B.T.U./(Ft.)(°F)(HR)
F – Freezing Index in Degree-Days
L – Average Latent Heat in B.T.U./Ft.³
C – Average Volumetric Heat in B.T.U./(Ft³x°F)
v_o – Mean Annual Air Temperature in °F
t – Duration of Freezing Index in Days
d – Thickness of Insulation Layer in Feet

An average value for thermal conductivity (k) = 1.5 B.T.U./(Ft.)(°F) (HR.), is used throughout these calculations.

Value for "d" used in Equation 158 is thickness of topsoil in feet.

NOTES:

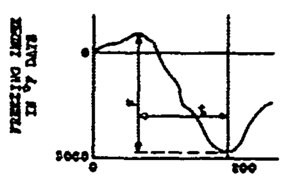
(I) Pavement types are as follows:
B.C. – Bituminous Concrete.
P.C.C. – Portland Cement Concrete.
T.S. – Topsoil (Turfed areas only).

(II) Values used for water content and density are for freezing period when available. Exceptions are noted as follows:
* – Values for Normal Period.
** – Values for Frost Melting Period.
(ψ) – Assumed Values.
NF – Values for Non-frozen Subgrade soil. (Freezing Period)

(III) Soil classification for airfields except as follows:
C.R. – Crushed rock.
S.Cem– Soil cement.

(IV) Depths of freezing obtained from test pit observations except as follows:
TH – Depths of freezing obtained from Thermometer and Thermocouple observations.

► Closest value to observed depth.
◄ Value within ± 6 inches of observed depth.



Time in Days
Relationship between F & t

FROST INVESTIGATION
1945 - 1946

PREDICTION OF FROST
PENETRATION

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1946

TABLE 5

B

$$Q = \frac{k(v_1 - v_2)At}{b} = \frac{(v_1 - v_2)At}{b/k} = \frac{T}{R} At \qquad (3)$$

Q = total quantity of heat transferred in Btu's
A = area in sq ft
v_1 = temperature of one face of conducting layer
v_2 = temperature of other face of conducting layer
t = time in hr

When $A = 1$ and $t = 1$, $Q = T/R$.

The temperature gradient in the ground closely approximates a straight line during the thawing season. When time is measured in days and a one-square-foot area is considered, equation (3) may be written:

$$Q = 24 \frac{Tt}{R} = \frac{24I}{R} \qquad (4)$$

Q = total number of Btu's per thawing season
$I = Tt$ = maximum number of degree-days of thaw based on surface temperature.

I is the thawing index and is determined by a summation of the degree-days of thaw based on the average daily temperatures during the thawing season.

a. Correlation of air and surface temperatures. Since air temperatures are generally available and surface temperatures are not, a study has been made of data from Fairbanks, Alaska to determine the relation between a thawing or freezing index calculated from air temperature and indexes calculated from the temperatures of different types of surfaces with the thermocouples so installed that they were partially embedded in the surface. This study has resulted in correction factors for various types of surfaces. Data presently available indicate values for the correction factor as shown in Table 6 for the horizontal surfaces investigated. The method of determining the correction factors for the various surfaces investigated is shown on Plates 20 and 21. Air temperatures are based on data collected by the U. S. Weather Bureau at Weeks Field in 1947 and early 1948. Surface temperatures are those obtained at test sections in the Fairbanks Research Area during the same period. The correction factor is merely the ratio of the degree-days above or below zero°C for the surface temperature to the degree-days of the air temperature during the same period. The degree-days are most simply obtained by planimetering the area between the zero °C line and the air or surface temperature curve. Studies of the correction factor are being continued for the succeeding year's observations. These data indicate that, on the average, the ground surface temperature under a cover of trees, brush and moss is only one-third as high above freezing as the air temperature during the thawing season. Bituminous surface temperatures averaged twice as high above freezing as the air temperatures during the same period. Snow was removed from the bituminous, concrete and gravel surfaces and left in place on the other surfaces. Further studies should be made to verify and increase the scope of these correction factors.

b. Heat flow into the ground. The heat which flows into the ground thaws

TABLE 6

COMPUTATION OF CORRECTION FACTORS FOR VARIOUS SURFACES IN FIELD RESEARCH AREA SUMMER 1947 AND WINTER 1947-1948

Type of Surface	Area and Section Used	Summer 1947					Winter 1947-48				
		Degree-Days Above 32° F				Correction Factor	Degree-Days Below 32° F				Correction Factor
		Air Temp	Period Covered	Surface Temp	Period Covered		Air Temp	Period Covered	Surface Temp	Period Covered	
1. Spruce trees, brush and moss over peat soil	Area 1-Sect. A	3055	4-13-47 to 9-30-47	1130	5-12-47 to 10-6-47	0.37	5042	9-30-47 to 5-3-48	1430	10-6-47 to 5-10-48	0.29
2. Cleared of trees and brush but with moss in place over peat soil	Area 1-Sect. B	3055	4-13-47 to 9-30-47	2220	4-28-47 to 10-6-47	0.73	5042	9-30-47 to 5-3-48	1245	10-6-47 to 4-22-48	0.25
3. Silt loam cleared and stripped of trees and vegetation	Area 1-Sect. C	3055	4-13-47 to 9-30-47	3720	4-21-47 to 10-6-47	1.22	5042	9-30-47 to 5-3-48	1660	10-6-47 to 5-3-48	0.33
4. Gravel	Area 2-Sect. RN-3	3055	4-13-47 to 9-30-47	6090	4-11-47 to 10-14-47		5042	9-30-47 to 5-3-48	3840	10-14-47 to 5-3-48	
	Sect. RN-26			6140	4-6-47 to 10-10-47				3160	10-10-47 to 4-28-48	
				Avg = 6110		2.00			Avg = 3500		0.70
5. Concrete	Area 2-Sect. RN-16	3055	4-13-47 to 9-30-47	6320	4-6-47 to 10-11-47		5042	9-30-47 to 5-3-48	3730	10-11-47 to 4-27-48	
	Sect. RN-17			5650	4-4-47 to 10-11-47				3800	10-11-47 to 4-29-48	
	Sect. RN-18			6160	4-3-47 to 10-11-47				4090	10-11-47 to 4-13-48	
	Sect. RN-23			6520	4-5-47 to 10-11-47				4280	10-11-47 to 4-13-48	
	Sect. RN-24			6360	4-3-47 to 10-11-47				3500	10-11-47 to 4-25-48	
				Avg = 6202		2.03			Avg 3880		0.77
6. Bituminous	Area 2-Sect. RN-2	3055	4-13-47 to 9-30-47	6560	4-8-47 to 10-13-47		5042	9-30-47 to 5-3-48	3650	10-13-47 to 4-29-48	
	Sect. RN-15			6450	4-10-47 to 10-10-47				3950	10-10-47 to 4-29-48	
	Sect. RN-25			6980	3-29-47 to 10-12-47				3290	10-12-47 to 4-4-48	
				Avg = 6663		2.19			Avg = 3630		0.72

Note: Snow was not removed from Surfaces 1, 2, and 3.
Snow was removed from Surfaces 4, 5, and 6.

frozen ground and raises the temperature of both thawed and frozen ground. If the heat which raises the soil temperature is ignored, a small error is introduced. This error is one of safety as far as design is concerned since it results in a calculated depth of thaw greater than the actual thaw. Considering only the latent heat of fusion, the number of Btu's per sq ft of area required to thaw the soil to depth "h" is:

$$Q = xL \tag{5}$$

x = depth of thaw
L = latent heat of fusion of water per cu ft of soil (143.4 Btu per lb of water)

$$L = 1.434\ wd$$

w = water content of the soil in percent of dry weight
d = dry density of the soil in lb per cu ft.

In the case of one thawing layer, the average resistance during the period that thaw is taking place may be written

$$\frac{R}{2} \text{ or } \frac{x}{2k}$$

The equation for the depth of thaw in one homogeneous soil layer is derived by equating (4) and (5) and using the average resistance:

$$Q = xL = \frac{24I_g}{R/2} = \frac{24I_g}{x/2k} = \frac{48kI_g}{x} = \frac{48kI_aC}{x} \tag{6}$$

I_g = thawing index based on ground surface temperature
I_a = thawing index based on air temperature
C = correction factor for a specific surface in equation $I_g = CI_a$.

$$x = \sqrt{\frac{48kI_aC}{L}} \tag{7}$$

Equation (7) is the same as Equation 83 in Addendum No. 1, 1945-1947, to Report on Frost Investigation 1944-1945, published by Frost Effects Laboratory, New England Division, October 1949, with the addition of the correction factor.

c. Depth of thaw in ground. The depth of thawing in ground composed of one or more different strata of materials may be computed very closely by determining the part of the annual corrected thawing index required to melt the ice in the voids of each stratum. The summation of these partial indexes in the various strata, equal to the annual corrected thawing index for the locality and existing ground surface, may be used to determine the depth of thaw. From (6) the partial index required to melt the ice in the top layer is:

$$I_1 = \frac{L_1 b_1}{24} \times \frac{R_1}{2}$$

where L_1 = latent heat of water per cu ft of soil.

b_1 = thickness of soil layer in ft

$R_1 = \frac{b_1}{k_1}$ = thermal resistance of the soil layer

k_1 = thermal conductivity of the soil layer.

The partial index required to melt the ice in the second layer is:

$$I_2 = \frac{L_2\, b_2}{24}\left(R_1 + \frac{R_2}{2}\right) \tag{9}$$

The partial index required to melt the ice in the "n"th layer is:

$$I_n = \frac{L_n\, b_n}{24}\left(\Sigma R + \frac{R_n}{2}\right) = \frac{L_n\, b_n}{24}\left(\Sigma R + \frac{b_n}{2k_n}\right) \tag{10}$$

The summation of partial indexes $I_1 + I_2 + \text{---}\ I_n$ is equal to the annual corrected thawing index. The total depth of thaw "x" is equal to $b_1 + b_2 + \text{---} + b_n$. The term b_n may be equal to or less than the thickness of the "n"th layer.

d. Sample computation of depth of thaw. A sample computation of depth of thaw in ground composed of several different soil layers is given in Table 7. The

TABLE 7

COMPUTED DEPTH OF THAW
FAIRBANKS RESEARCH AREA -- RUNWAY TEST SECTION RN-4

Layer	Material	"b" Thickness of Layer in ft	"d" Dry Density of Soil lb/cu ft	"w" Water Content of Soil in % of Dry Wt	"L" 1.434 wd Volumetric Latent Heat of Fusion	"k" Thermal Conductivity Btu/sq ft/hr/°F/ft	$R = \frac{b}{k}$ Thermal Resistance	ΣR	$\Sigma R + \frac{R_n}{2}$	I = Thawing Index $I_1 = \frac{L_1\, b_1}{24} \times \frac{R_1}{2}$ $I_n = \frac{L_n\, b_n}{24} \times (\Sigma R + \frac{R_n}{2})$ Increment	Summation
Thawing index for 1947 based on air temperature = 3055. Corrected = 3055 × 2.19 = 6690.											
1	Asphalt	0.4	150	0.0	0	$\frac{10.3}{12} = 0.86$	0.47	0.0	0.24	0	0
2	Gravel (GW)	3.8	143	3.7	759	$\frac{22.0}{12} = 1.83$	2.08	0.47	1.51	$\frac{759 \times 3.8 \times 1.51}{24} = 181$	181
3	Silt (MH)	2.5	99	27.7	3932	$\frac{10.0}{12} = 0.83$	3.02	2.55	4.06	$\frac{3932 \times 2.5 \times 4.06}{24} = 1665$	1846
4	Peat	1.5	25	81.9	2936	$\frac{2.0}{12} = 0.17$	8.80	5.57	9.97	$\frac{2936 \times 1.5 \times 9.97}{24} = 1824$	3670
5	Silt & Peat	1.0	62	50.0	4445	$\frac{6.0}{12} = 0.50$	2.00	14.37	15.37	$\frac{4445 \times 1.0 \times 15.37}{24} = 2840$	6510
6	Silt & Peat	$x = \frac{0.05}{9.25}$	78.2	39.5	4429	$\frac{7.5}{12} = 0.63$	$\frac{x}{0.63}$	16.37	$16.37 + \frac{x}{1.26}$	$\frac{4429 \times x \times (16.37 + \frac{x}{1.26})}{24} = 180$	6690

Solving for x in Layer 6

$$\frac{4429}{24} \times x \times \left(16.37 + \frac{x}{1.26}\right) = 180 \qquad 185x\left(16.37 + \frac{x}{1.26}\right) - 180 = 0 \qquad 3028x + 146.8x^2 - 180 = 0$$

$$x^2 + 20.6x - 1.2 = 0 \qquad x = \frac{-20.6 \pm \sqrt{20.6^2 + 4.8}}{2} = -20.6 \pm \sqrt{429} = \frac{-20.6 \pm 20.7}{2} = 0.05$$

Note: Computed depth = total of column "b" = 9.25 ft. Actual depth = 10.2 ft.

thawing index for 1947 based on air temperatures at Fairbanks was 3055. The correction factor for a bituminous surface is 2.19. Values for thickness, density, and moisture content of the various soils are based on field tests. Values of thermal conductivity were obtained from Plates 4 and 6 and the final report of the University of Minnesota on the tests of thermal properties. The computed and actual field test data are plotted in Plate 22.

e. Volumetric heat. The above analysis does not take into account the heat necessary to raise the ground temperature above the freezing point. In most cases, this additional heat is of relatively small importance as compared with the heat required to melt the ice in the soil. However, under those conditions where the soil contains little moisture, the available heat energy is used principally in raising the soil temperature. Such a condition can occur where a porous gravel fill is placed above the natural groundwater table. A relatively small amount of heat is expended in heating the dry gravel while a large amount of heat is expended in melting ice below the groundwater table. The amount of heat used in raising the temperature of moist soil one degree Fahrenheit is:

$$\frac{1.0\ wdb}{100} + cdb \tag{11}$$

where b = thickness of soil layer in ft
w = water content of the soil in percent of dry weight
d = dry density of the soil in lb per cu ft
c = specific heat of soil
1.0 = specific heat of water.

The amount of heat required during the thawing season to raise the temperature of the moist soil to the mean temperature during the period is equal to:

$$\frac{Idb}{2t}\left(\frac{w}{100} + c\right) \tag{12}$$

where I = thawing index in degree-days
t = number of days in thawing period

A more exact calculation of depth of thaw would include the above factors in equation (6). For solutions in which both the latent heat of fusion and the volumetric heat capacity of the soil are included, reference is made to Table 8 and Appendix A of Addendum No. 1, 1945-1947, to Report on Frost Investigation 1944-1945, published by Frost Effects Laboratory, New England Division, October 1949.

f. Computed depths of thaw in various soils. Computed depths of thaw for uniform layers of peat, silt loam, sand, and gravel from Northway and the Research Area near Fairbanks, Alaska are shown in Plate 23. It may be noted that for a given density condition, large variations in moisture content have very little effect on the depth of thaw in peat and silt loam and that the variation in depth between the high and low density conditions is only a few feet. From the knowledge of the fact that the thermal conductivity increases generally as the moisture content increases, it may appear strange that the

depth of thaw does not also increase as the moisture content is increased. However, the latent heat of fusion capacity of the soil varies in proportion to the moisture content and, in the case of the peat and silt loam studied, acts to very nearly compensate for the increase in thermal conductivity. In the cases of sand or gravel, the latent heat of fusion capacity increases faster than the effect of thermal conductivity and, as a result, the depth of thaw is less in wet than in dry sand or dry gravel. The effect of density on depth of thaw is very pronounced in sand or gravel with a range of about 15 ft from maximum to minimum. High density in either the silt loam or gravel causes thawing to greater depths than does low density. It is evident that greater depths of thaw are likely to occur in coarse-grained material such as gravel than in fine-grained material such as silt loam.

g. Effects of fills on frost action. In normal construction operations, it is usual practice to place fills at the highest practicable density to support structural loads. Such fills, which are generally coarse grained, will produce conditions most suitable for deep thawing. The tests and studies reported on herein indicate that it is impracticable to construct fills under runways or large buildings to sufficient depth to entirely prevent thawing below the fills. Frost heaving in itself is not generally damaging to a runway or highway if it is uniform. However, where the subgrade is not uniform in soil characteristics, differential heaving can be expected. Although it may be somewhat difficult to operate traffic over pavements where differential heaving has taken place, the most serious effect of the frost action is due to the loss in bearing capacity of the subgrade during the period that the ice lenses are melting. Since frost action in soils depends, among other things, on the grain size, available water supply, and capillarity of the soil, it is possible, according to Beskow, to reduce frost action by constructing in the fill a well-drained layer of coarse-grained soil having low capillarity. The effect of this layer is to break the capillary flow of water to any fine-grained soil placed above it. In general, the fine-grained material is a better thermal insulator than the coarse-grained. Thus, a combination of layers of fine and coarse materials may, under certain circumstances and with proper drainage techniques, prove to be the most satisfactory solution. Medium sand has a capillarity of only a few inches; therefore, a one-foot layer of this material, if well drained, would normally be ample to insure that the fine-grained material placed above did not receive sufficient water to form ice lenses and cause heaving. Frost heaving is not caused in any soil by the water normally contained in the voids but only by the water drawn from groundwater reservoirs by capillarity. It is known that water exists in soil in the form of vapor and moves by diffusion from points of high to low vapor pressure. Such pressure differences occur as the result of temperature differences or differences in capillary tension between surfaces. Temperature differences during the fall when freezing occurs from the ground surfaces tend to cause vapor travel in the soil to the cold surface. In the spring with the warming of the ground, surface vapor travel is downward to the colder interior. According to Beskow[5], "the diffusion due to temperature difference is so small, that for water flow in frost-heaving soils (being only a few mm per day), it is of no importance".

h. Thawing under buildings. Thawing under a building depends to a large extent on the size of the building. A long, narrow building will have a lesser

depth of thaw than a square building with the same ground area because of the differences in heat flow laterally. In general, the depth of thaw in permafrost under a building subject to a uniform interior heat condition is proportional to the square root of the time during which the heat condition is maintained. This may be deduced from the development of the formula:

$$x = \sqrt{\frac{48kTt}{L + \frac{Td}{2}\left(\frac{w}{100} + c\right)}}$$

$$24I = 24Tt = \left[Lx + \frac{Tdx}{2}\left(\frac{w}{100} + c\right) \right] \frac{R}{2} \tag{13}$$

$$24Tt = x \left[L + \frac{Td}{2}\left(\frac{w}{100} + c\right) \right] \frac{x}{2k} \tag{14}$$

$$x = \sqrt{\frac{48kTt}{L + \frac{Td}{2}\left(\frac{w}{100} + c\right)}} \tag{15}$$

where I = total thawing index in degree-days up to any given time "t"
T = temperature difference between building floor and permafrost surface.

i. <u>Sample calculation of thawing under a building.</u> A sample calculation using this formula and available data from observations of the hangar at Northway Airfield, Alaska is as follows, based on uniform soil conditions and the assumption that there is no lateral heat flow:

Sandy soil $w = 25\%$ $d = 93$ lb/cu ft $k = \frac{19.5}{12} = 1.62$ $c = 0.17$

$T = 60^\circ$ (at floor surface) $- 32^\circ = 28^\circ$

$L = 143.4\ wd = 143.4 \times \frac{25}{100} \times 93 = 3334$ Btu per cu ft.

The hangar was constructed in 1943 and heating started on 1 November 1943.

(1) Computed depth of thaw to 1 November 1945 = 730 days after construction.

$$x = \sqrt{\frac{48 \times 1.62 \times 28 \times 730}{3334 + \frac{28 \times 93}{2}(.25 + .17)}} = \sqrt{\frac{1,590,000}{3334 + 560}} \doteq \sqrt{408} = 20.2 \text{ ft}$$

Actual depth was 20 ft.

(2) Computed depth of thaw to 1 November 1946 = 1095 days after construction.

$$x = 20.2\sqrt{\frac{1095}{730}} = 20.2 \times 1.225 = 24.8 \text{ ft}$$

Actual depth was 22.5 ft.

(3) Computed depth of thaw in 10 years, t = 3650 days.

$$x = 20.2\sqrt{\frac{3650}{730}} = 20.2 \times 2.24 = 45.2 \text{ ft}$$

(4) Computed depth of thaw in 30 years, t = 10,950 days.

$$x = 20.2\sqrt{\frac{10,950}{730}} = 20.2 \times 3.88 = 78.4 \text{ ft.}$$

A graph of these computations is shown in Plate 24. The size of this building is 162 by 208 ft and the concrete floor was placed directly on a sand and gravel fill. For a building with a large ground area, these calculated depths would be very nearly correct at the center of the area. However, lateral heat flow would reduce the accuracy at the edges.

j. Heat transfer through building floors. Calculations have been made to determine the over-all coefficients of heat transmission for various types and thicknesses of floor construction in buildings with relatively large floor areas in which edge effects are minimized. This coefficient is equal to the heat transmission through the floor in Btu per hr per sq ft per °F. It is computed from the equation:

$$U = \frac{1}{R_t} = \frac{1}{R_1 + R_2 + R_3 + --- + R_n}$$

where $R = \frac{x}{k}$ or $\frac{1}{f}$ or $\frac{1}{a}$ = thermal resistance.

R_t = total thermal resistance
R_1 = thermal resistance of layer no. 1
x = thickness of material
k = thermal conductivity of material
f = film or surface conductance
a = air space conductance.

The above equation is a standard equation which may be found in any book on heat transfer studies, such as the "Heating, Ventilating, and Air Conditioning Guide".[12] The results of these calculations are shown in Plate 25. It is evident that a still air space under the floor very materially reduces the heat flow to the ground especially for the thinner floor thicknesses. Wood floors and insulation are also effective in further reducing the heat flow. Where it is desired to further reduce the heat flow into the ground, it can be accomplished by circulating cold air between the floor and the ground. The required velocity of air movement can be computed as follows:

(1) Heat flow through a composite floor = $AU(t_1 - t_2)$

A = area in sq ft
U = over-all coefficient of heat transmission
$(t_1 - t_2)$ = temperature difference between surfaces.

(2) Heat removal by air movement = $c_a\, q\, (t_3 - t_4)$

q = air volume in cu ft per min

c_a = specific heat of air = 0.019 at 32° F
$(t_3 - t_4)$ = temperature difference of entering and leaving air.

(3) If it is assumed that $(t_1 - t_2) = 10\,(t_3 - t_4)$ and A = 1 sq ft, then: 10U = 0.019q or U = 0.0019q and velocity V = q. The required air velocity to dissipate the heat conducted through the floor = $\frac{U}{0.0019}$. For a 2-in. concrete floor:

$$U = \frac{1}{\frac{1}{f} + \frac{x}{k} + \frac{1}{a}} = \frac{1}{\frac{1}{1.65} + \frac{2}{12.6} + \frac{1}{0.94}} = .547$$

$$V = \frac{.547}{.0019} = 288 \text{ ft per min or } 4.8 \text{ ft per sec.}$$

33. CONDITIONS NECESSARY FOR THE EXISTENCE OF PERMAFROST. For permafrost to exist without change from year to year, the average annual temperature gradient in the ground in a homogeneous soil layer below maximum seasonal thaw must remain the same. Since heat flows from the depths of the earth to the surface, the temperature gradient must be negative toward the surface as heat always flows from warmer toward colder regions. The depth of the bottom of permafrost is a function of the natural temperature gradient in the ground and of the mean annual surface temperature. When the mean annual surface temperature and the temperature gradient in the soil are known, a projection of the gradient to 32° F gives the approximate depth of permafrost, provided that the soil characteristics in the projected depth are the same as in the known depth.

34. EQUATION FOR UNIDIRECTIONAL HEAT FLOW. If the mean annual temperature of the surface or any soil layer below the surface is raised, the heat balance is destroyed and the natural temperature gradient is changed. The soil layers change temperatures according to the equation for unidirectional flow:

$$\frac{\delta V}{\delta t} = \frac{k}{C} \quad \frac{\delta^2 V}{\delta x^2}$$

V = temperature
t = time
k = thermal conductivity
C = volumetric heat capacity
x = depth

The new temperature gradient from the bottom to the top of permafrost decreases the heat flow from the bottom and, since the heat flow from the depths of the earth does not change, less heat flows to the ground surface from the bottom of permafrost than is received there, resulting in thaw at the latter plane. In other words, raising the mean annual temperature of the earth's surface results in decreasing the thickness of permafrost. This thawing at the bottom of permafrost is very slow, but it continues until the heat flowing to and from the bottom of permafrost is in equilibrium.

35. ANNUAL CYCLE OF GROUND TEMPERATURE CHANGES. During the annual cycle of temperature change in the top layers of the earth, heat flows into the earth as long as the surface temperature is higher than that of the layer adjacent to the surface and heat flows out when the reverse is true. This means that heat flows into the ground from shortly after the time of coldest surface temperature to shortly after the time of warmest

temperature. To maintain the same mean annual temperature, the surface possesses the same amount of heat energy on the average from year to year. Expressed another way, the heat lost by the surface by any method whatsoever must equal the heat gained.

36. HEAT LOSS BY SURFACE CONDUCTANCE. Heat is lost by the surface to the atmosphere and outer space by surface conductance during all of the year. The definition of surface conductance makes no distinction as to the method by which heat is transferred from a surface to the air; conduction, convection, and radiation all play a part. An increase in wind velocity produces an increase in surface conductance. When a cold wind blows, the so-called "chill effect" is noticeable; objects and people are cooled rapidly. When air is moist, its specific heat is greater, which means that a cool, moist wind can lower the temperature of a ground surface more than a cool, dry wind because the heat that passes from the surface to the air does not raise the temperature of the moist air as much as it would the dry air. The surface conductance includes radiation, and since the energy radiated from a body is a function of the fourth power of its absolute temperature, the surface conductance of the ground surface is higher in the summer than in the winter. Surface conductance tends to equalize surface temperature and air temperature. However, other factors such as moving air masses, evaporation, transpiration, daily radiation cycles, snow cover, latent heat, type of surface, localized shading, reflected radiation, cycles of low and high atmospheric pressure, and so forth, will make surface temperatures somewhat different from the air temperatures as observed by the Weather Bureau.

37. SIGNIFICANCE OF SURFACE TEMPERATURES. As long as there is a surface temperature higher than 32° F, it is possible that frozen soil is melting below the surface. Even though the surface temperature is below 32° F at the end of the thawing season, there may be heat stored in the ground between the surface and the thawing layer which causes thawing to continue for some time. As long as the surface temperature is below 32° F, it is possible that soil is freezing.

38. EQUATIONS FOR HEAT FLOW DURING THAWING AND FREEZING SEASONS. Near the end of the freezing season, in regions of permafrost, the seasonally thawed layer generally has been completely frozen, and the ground is being cooled below the freezing point. To maintain the level of the upper surface of the permafrost layer, it is only necessary to freeze back in winter that which has thawed during the previous summer. However, if the mean annual temperature of the ground surface is raised, permafrost will melt upward from the bottom because of the decreased gradient in the permafrost. Assuming that the temperature of the soil below seasonal freeze is 32° F, that the temperature gradients in homogeneous ground in the active layer during the thawing season and the freezing season are approximately straight lines (an assumption which ground temperature readings show to be reasonable), and that the depth of the frozen ground at the end of the freezing season is equal to the depth of the ground thawed during the thawing season, then the approximate amount of heat which flows into the ground during the thawing season per square foot of level ground is:

$$Q_u = \frac{k_u G_u t_u (24)}{x/2} = \frac{48 k_u I}{x}$$

Q_u = total amount of heat in Btu's which enters the ground during the period the ground thaws

k_u = thermal conductivity of the thawed soil

G_u = average surface temperature in °F during the thawing season minus 32

t_u = number of days the surface temperature is above 32° F

x = maximum depth of thaw in ft
$x/2$ = average depth of thaw during season
24 = number of hr in a day
$I = G_u t_u$ = thawing index or number of degree-days of thaw.

Similarly, the equation for the heat flow during the freezing season may be written:

$$Q_f = \frac{k_f G_f t_f (24)}{x/2} = \frac{48 k_f F}{x}$$

Q_f = total amount of heat which flows out of the ground during the freezing season
k_f = thermal conductivity of the frozen soil
G_f = 32 minus the average surface temperature during the freezing season
t_f = number of days the surface temperature is below 32° F
$F = G_f t_f$ = freezing index or number of degree-days of freeze.

Since the heat necessary to thaw layer x is equal to the heat given up in freezing it, and any other heat involved is neglected as an approximation, the preceding equations may be combined:

$$k_u I = k_f F$$

This means that, under the conditions given by the equation, no permafrost exists and seasonal thaw is equal to the seasonal freeze.

39. EXISTENCE OF PERMAFROST. When seasonal thaw does not melt all of the frozen ground, permafrost does exist, and:

$$k_f F > k_u I$$

$$\frac{k_f}{k_u} > \frac{I}{F}$$

For Fairbanks silt loam, conductivity values determined by experiment are:[10]

Dry Density lb/cu ft	Moisture Content Percent	Mean Temp °F	Thermal Conductivity Btu/sq ft/hr/°F/in.
93.3	24.4	40.0	9.55
93.3	24.2	24.9	13.23

Then $\frac{k_f}{k_u} = \frac{13.23}{9.55} = 1.39$, and $\frac{I}{F}$, the ratio of thawing and freezing indexes based on surface temperatures, must be less than 1.39 for permafrost to exist. It should be noted that the ratio can be greater than 1.00. In other words, permafrost can exist even though the thawing index is greater than the freezing index.

40. SOIL MOISTURE CONTENT VERSUS THERMAL CONDUCTIVITY. The thermal

conductivity of ice is approximately 16 Btu per sq ft per hr per $^{\circ}F$ per in. and of water 4 Btu per sq ft per hr per $^{\circ}F$ per in. which makes the ratio of the two 4 to 1. The conductivity of frozen soil is a function of the moisture content. Under most conditions, the greater the moisture content, the greater is the ratio of the thermal conductivity of the soil frozen to that of the soil thawed. The preceding statements being true, the ratio of thawing index to freezing index may be larger for higher moisture contents than in the above example and not violate the conditions necessary for the existence of permafrost. Plates 26 and 27 show how the ratio of the thermal conductivity at 25° F to the thermal conductivity at 40° F varies with moisture content in silt loam and sandy soils, respectively. It may be seen that moisture content is definitely a factor in causing permafrost.

41. RATIO OF THAWING INDEX TO FREEZING INDEX, FAIRBANKS. It has been found by study of the Weather Bureau records at Fairbanks, Alaska that the ratio of $\frac{I_a}{F_a}$ based on air temperatures was $\frac{3055}{5042}$ or 0.61 for the summer of 1947 and the winter of 1947-1948, see Plate 28. For bituminous surfaces, the corrected thawing index is 2.19 × 3055 or 6690, and from available information, it is known that the corrected freezing index is 0.72 × 5042 = 3630. The ratio $\frac{I}{F} = \frac{6690}{3630} = 1.84 = \frac{k_f}{k_u}$. To maintain permafrost in silt loam soils under these conditions, very high moisture contents are required. See Plates 26 and 27 for values of $\frac{k_f}{k_u}$. Plate 28 shows in graphic form freezing and thawing indexes at Weeks Field, Fairbanks, Alaska during the period that weather records have been obtained.

42. EQUATIONS FOR THAW AND FREEZE IN SATURATED GRAVEL. Assuming the thickness of thaw in the saturated gravel to be layer x and the heat lost during the freezing season to be just sufficient to freeze back layer x, the approximate amount of heat conducted per square foot may be written:

$$Q_f = \frac{G_f t_f (24)}{R_f} = \frac{24F}{r_1 + r_2 + \frac{r_f}{2}} = \frac{24F}{\Sigma r + \frac{x}{2k_f}}$$

$$Q_u = \frac{G_u t_u (24)}{R_u} = \frac{24I}{r_1 + r_2 + \frac{r_u}{2}} = \frac{24I}{\Sigma r + \frac{x}{2k_u}}$$

and $Q_f = Q_t$.

$$\frac{24F}{\Sigma r + \frac{x}{2k_f}} = \frac{24I}{\Sigma r + \frac{x}{2k_u}}$$

$$\frac{I}{F} = \frac{\Sigma r + \frac{x}{2k_u}}{\Sigma r + \frac{x}{2k_f}}$$

Σr = thermal resistance down to the thawing layer
x = thickness of the thawing or freezing layer
k_u = thermal conductivity of layer x thawed
k_f = thermal conductivity of layer x frozen.

For permafrost conditions:

$$Q_f > Q_t \text{ and } \frac{\Sigma r + \frac{x}{2k_u}}{\Sigma r + \frac{x}{2k_f}} \text{ should be greater than } \frac{I}{F}.$$

43. TEMPERATURE GRADIENT VERSUS THICKNESS OF P"RMAFROST LAYER. In general, the natural temperature gradient in the ground is the be.t means of estimating the thickness of permafrost. Permafrost melts upward from the bottom when the gradient in the ground is decreased. The gradient is changed by changing materials at the surface because any change whatsoever affects the ratio of thermal conductivities and indexes. Depth of thaw is a function of the amplitude of surface temperature oscillation. An estimate of the maximum rate of thaw of permafrost upward from the bottom may be made. Under natural conditions, it may be assumed that the temperature gradient in the permafrost from about 30 ft down is stable and that the heat flow to the surface of the earth is the same as the heat flow from lower depths to the bottom of permafrost. It is recognized that this assumption is not strictly true because of the changes being made in the earth's climate. When the thermal gradient in permafrost is diminished to zero by causing thaw to exceed freeze at the surface, a condition for maximum rate of thaw at the bottom has been brought about. All the heat which flows to the bottom of permafrost from below thaws the frozen ground, and this heat is equal to:

$$dQ_1 = dQ_2 = \frac{dT}{dx} kAdt = Ldx_1 = 1.434\ wddx_1$$

dQ_1 = heat flow to the bottom plane surface of permafrost from below
dQ_2 = heat flow to the surface of the earth from the bottom, plane surface of permafrost when gradients are stable
$\frac{dT}{dx}$ = thermal gradient in permafrost
k = thermal conductivity of permafrost at point where thermal gradient is determined
A = area = 1 sq ft generally
dt = time in hr
143.4 = latent heat of fusion of 1 lb of ice in Btu's
w = moisture content of soil in percent at the bottom, plane surface of permafrost
d = dry density of soil at the bottom, plane surface of permafrost.

The rate of thaw may be written:

$$\frac{dx_1}{dt} = \frac{k}{1.434wd} \quad \frac{dT}{dx} \qquad \Delta x_1 = \frac{k}{1.434wd} \quad \frac{dT}{dx} \quad \Delta t$$

At Umiat, these approximate data were estimated:

$$\frac{dT}{dx} = \frac{1^\circ F}{58 \text{ ft}} \quad \text{(from temperature observations)}$$

w = 30 percent (by estimation)
d = 85 lb per cu ft (by estimation)
k = 1.08 Btu per sq ft per hr per $^\circ$F per ft (from chart, Plate 5)

Approximately

$$\Delta x_1 = \frac{1.08}{1.434\,(30)(85)} \times \frac{1}{58} \times (365) \times (24) = 0.044 \text{ ft.}$$

which means that the approximate maximum rate of thaw is 0.044 ft per year, or that it would take at least 22.7 years to thaw one foot of permafrost upward from the bottom by means of heat from the earth. This value is meant only to give the order of magnitude because of the nature of the data.

44. SUMMARY. The theory for depth of thaw developed in this section is used in the following section to calculate the depth of thaw in certain parts of the Fairbanks Research Area at Fairbanks, Alaska. These calculated depths are compared with observed depths of thaw. In most cases, the compared values are very nearly the same, and it is considered that the equation used is substantiated. In order to extend this study, more information is required concerning the moisture, density, and thermal conductivity of soils in place adjacent to the temperature wells at the various field installations in Alaska.

IX Analysis of Observations -- Fairbanks Research Area

45. GENERAL. Thermal diffusivity is the property of a material which permits it to diffuse or disperse heat in all directions and is an index of the facility with which a material will undergo temperature change. Mathematically, it may be expressed as $\frac{k}{cd}$.

This equation shows that those factors which increase the conductivity of a material also increase the diffusivity, while factors which increase the specific heat and density reduce the diffusivity. Variations in density have a direct effect on thermal conductivity and, as stated above, have an inverse effect on diffusivity. In the case of soils, the resultant effect of increases in density is to cause substantial increases in diffusivity especially at the lower moisture contents. The effect of freezing a soil is to increase the diffusivity in proportion to the quantity of moisture it contains.

46. GROUNDWATER. Plate 29 shows typical groundwater contours superimposed on a topographic map of the Fairbanks Research Area. The general slope of the groundwater surface is essentially the same as the ground surface. During 1948, groundwater was at higher levels than in 1947 because of greater rainfall. In 1947, the groundwater level generally followed the recession of seasonal frost. Frequently, no free water was encountered above the frozen ground, although the soil had a high moisture content. Studies of groundwater data indicate that groundwater levels in fine-grained soils over permafrost fluctuate more rapidly than might be expected. It is probable that much of the groundwater flow is through earth cracks formed during extremely cold weather as well as through voids left after melting of ground ice.

47. MOISTURE CONTENT OF SOILS. In general, it may be stated that the moisture content of the silt soils in the Research Area varied between 25 and 50 percent at all depths except where peat was present. The effect of peat was to increase the moisture content up to 300 percent of the dry weight of the material depending on the amount of peat in the soil.

Area No. 1 -- Fairbanks Research Area

48. PURPOSE. Area No. 1 of the Fairbanks Research Area was constructed for the purpose of determining the effect of various surface conditions on heat transfer into the ground. The surface conditions included an undisturbed area with natural cover of vegetation including moss, brush, and spruce trees; an area with brush and trees cleared; an area stripped of all vegetation; and a concrete area composed of three sections with natural, white, and black surfaces.

49. GROUND TEMPERATURES. Detailed information on the variation in ground temperatures for the various test sections is contained in Appendix III. Depths of thaw below the ground surface on the first of each month during the thawing seasons of 1947 and 1948 are shown in Table 8.

TABLE 8

DEPTH OF THAW

FAIRBANKS RESEARCH AREA NO. 1

1947 AND 1948

Date	Total Depth of Thaw in Feet Below Surface of Section					
	A	B	C	DB	DN	DW
1947	Natural	Cleared	Cleared and Stripped	Black Concrete	Natural Concrete	White Concrete
1 May	-	0.0	0.8			
1 June	1.5	1.6	1.9			
1 July	2.5	3.0	3.0			
1 Aug	3.0	4.0	4.3			
1 Sept	3.2	4.2	5.1			
1 Oct	2.9	4.3	5.7			
1 Nov	-	3.7	6.0			
Maximum	3.2	4.3	6.0			
1948						
1 May	0.0	0.0	0.0	-	0.0	-
1 June	1.1	1.8	2.0	-	5.1	-
1 July	3.3	3.7	4.2	6.5	6.1	6.7
1 Aug	3.6	4.8	5.6	7.7	7.5	7.6
1 Sept	4.0	5.0	6.1	8.2	8.1	8.1
1 Oct	4.0	5.0	6.3	7.5	7.2	7.9
1 Nov	0.0	0.0	5.2	0.0	0.0	0.0
Maximum	4.0	5.0	6.3	8.2	8.1	8.1

50. CORRELATION OF THEORY WITH TEST DATA. Section A of this area was left in its natural condition with trees, brush, moss, and other vegetation in place. There was a deep penetration of temperatures below freezing in this section and relatively shallow penetration of temperatures above freezing with the result that permafrost extended to a point between 3 and 4 ft from the surface. Trees and brush were removed from Section B, but the moss and other vegetation were left in place. In Section B, temperatures above freezing penetrated to a depth between 4 and 5 ft below the surface while, during the winter, a temperature of one degree below freezing penetrated only to about 5 ft. In Section C, all trees and vegetation were completely removed. In this section, temperatures above and below freezing penetrated to about 6 ft below the surface. It is considered that the temperature conditions in Area No. 1 can be correlated to changes in soil diffusivity resulting from the removal of natural vegetative insulation. Where all of the trees and vegetation are in place, as in Section A, the shallow depth of ground thawed during the summer freezes rapidly in the fall joining with the permafrost to form a continuously frozen mass to relatively great depth. Because of the continuously frozen condition, the diffusivity of the ground is high and the heat moves out of the ground to great depths and at a comparatively rapid rate during the winter. The trees in this section, which are quite dense, shade the ground and probably absorb a large portion of the solar radiation received. Where the seasonal frost zone and the permafrost zone do not join until the latter part of the winter season, there is generally insufficient, intensely cold weather after that time to cause deep penetration of freezing temperatures. Somewhat greater depths of thaw were noted in Sections A, B, and C during 1948 than in 1947, probably because of greater ground moisture conditions and resultant greater thermal conductivity in 1948. It may be concluded from the results obtained in 1948 that concrete surface color whether black, gray or white under the test conditions has no appreciable effect on depth of thaw.

51. VERTICAL MOVEMENT. Vertical movement data collected from Area No. 1 at points shown on Plate 12 have been averaged for each section and are shown on Plates 30 and 31 for the period of observation from 22 November 1946 to 2 October 1948. The average annual range of vertical movement for the two years of record is shown in Table 9.

TABLE 9

AVERAGE ANNUAL RANGE OF MOVEMENT OF SECTIONS IN FEET

FAIRBANKS RESEARCH AREA NO. 1

Section	A Natural	B Cleared	C Stripped	DB Black Concrete	DN Natural Concrete	DW White Concrete
Fall 1946-Fall 1947	0.374	0.555	0.494			
Fall 1947-Fall 1948	0.288	0.538	0.302	0.362	0.363	0.353

It may be noted from the drawings that settlement coincides with the period of thaw and heave coincides with the period of freezing. Although the range of movement for Sections A, B, and C was different for each year, each of the sections apparently had an equal amount of heave and settlement during each year. The latter condition would indicate that the movements are seasonal. Data accumulated to date indicate the greatest movement in the cleared section, the least movement in the natural undisturbed section, with movement

in the stripped section approximately equal to the average of the two extremes during 1947 and approximately equal to the movement of the undisturbed section in 1948. An explanation for the observed order of vertical movement for the three sections is that Section A has the least depth of thaw and, therefore, the least volume change due to frost action. Section B has surface vegetation such as moss which is highly absorptive and more susceptible to ice lens formation than the underlying silt soil which is exposed in Section C. The average annual range of vertical movement of each of the three colored sections, DB, DN, and DW, are approximately equal. As previously noted, this is also the condition for the maximum depth of thaw. It is concluded that the effect of the surface colors used in the test were all substantially the same with regard to vertical movement, i.e., no color had an advantage over another.

Area No. 2 -- Fairbanks Research Area

52. PURPOSE. The 26 runway test sections in Area No. 2 were constructed to determine the effect of various pavement types, insulators, and base courses on ground temperatures. Differences in the sections are shown in Plate 13 and described in detail in Appendix III.

53. GROUND TEMPERATURES. Tables 10 and 11 show the total depth of thaw under each runway test section at the beginning of each month between 1 May and 1 November in 1947 and 1948, respectively. The maximum depths of thaw below the pavement surface, original ground surface, and final subgrade are also shown. Sections constructed during the winter or spring had somewhat less total depth of thaw during 1948 than sections constructed during the summer. It appears that no significance can be attached to this condition since the sections constructed during the summer generally had the least depth of thaw during the early part of the thawing season. It is concluded that the construction season has no appreciable effect on depth of thaw. Pavement surfaces tested all had substantially the same total depth of thaw. Sections containing insulators of various types which were constructed during the summer had, in four cases, about the same depth of thaw as an uninsulated section. In four cases, the insulated sections had greater total depth of thaw than the uninsulated section. The effect of the insulating layer on heat transfer at various times in 1947 and 1948 is shown in Plate 32. The data shown indicate a slight advantage through the use of P.C. Foamglas, however, the difference is not great, and there is some question as to whether the difference would warrant its use. In general, the insulating materials were not effective in reducing the depth of thaw as compared to uninsulated sections. Analysis of available data indicates that the effect of the insulators is to prevent heat transfer into the ground below and to hold heat above the insulation by increasing the temperature gradient through the insulation. Thus, the ground temperature below the insulation is cooler in summer and warmer in winter than if the insulation were not present. The net effect is that the mean annual ground temperature is about the same whether or not insulation is used. Where insulation is placed during the cold season as was the case in Section RN-11, cold is trapped below the insulation and, as a result the depth of thaw is reduced during immediately subsequent years until the surplus cold can be dissipated. While no data are available as to the moisture content of the soil above P.C. Foamglas insulation, it appears that it may be greater than if this insulation layer were not present due to the relative imperviousness of this material. Sand as well as sand and gravel base courses had essentially the same effect on depth of thawing. Base courses varying in design thickness from 2 to 12 ft did not reduce the depth of thaw penetration into the natural ground in proportion to the thickness of the base course. The range of the maximum depth of thaw below the final subgrade for these sections was from 4.4 to 7.8 ft in 1947 and from 5.2 to 7.3 ft in 1948. In comparison with the results obtained

TABLE 10

DEPTH OF THAW -- 1947
FAIRBANKS RESEARCH AREA NO. 2

Sec. No.	Construction Season	Surface	Insulation	Base Course Type	Base Course Design Thickness	Total Depth of Thaw -- Below Pavement Surface 1 May	1 June	1 July	1 Aug	1 Sept	1 Oct	1 Nov	Max	Height of Base Course Above Original Ground Surface	Maximum Depth of Thaw Below Original Ground Surface	Height of Base Course Above Final Subgrade	Maximum Depth of Thaw Below Final Subgrade
				Effect of Construction Season													
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	4.0	6.2	7.2	8.6	9.5	10.2	10.2	10.5	1.8	8.7	4.2	6.3
RN-25	Spring	5-in. Asphalt	None	Sand & Gravel	4 ft	4.1	6.4	7.5	8.7	9.8	10.3	10.3	10.3	3.4	6.9	4.3	6.0
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	3.5	6.1	7.3	8.8	9.7	10.3	10.0	10.4	1.4	9.0	4.4	6.0
RN-24	Spring	6-in. Concrete	None	Sand & Gravel	4 ft	3.5	5.8	6.8	7.9	9.7	10.4	10.3	10.3	3.4	6.9	4.6	5.7
RN-3	Summer	Gravel	None	Sand & Gravel	4 ft	3.3	5.9	6.8	8.1	9.1	9.6	8.1	10.0	1.8	8.2	4.3	5.7
RN-26	Spring	Gravel	None	Sand & Gravel	4 ft	4.2	5.5	7.2	8.8	9.9	10.0	10.0	10.0	3.5	6.5	4.7	5.3
RN-7	Summer	5-in. Asphalt	6-in. Cell Concrete (Med Den.)	Sand & Gravel	4 ft	3.9	6.0	7.8	9.1	9.8	10.2	10.4	10.4	1.5	8.9	4.2	6.2
RN-10	Winter	5-in. Asphalt	6-in. Cel. Concrete (Med Den.)	Sand & Gravel	4 ft				7.7	8.9	10.0	10.4	10.4	1.9	8.5	4.6	5.8
RN-6	Summer	5-in. Asphalt	6-in. P.C Foamglas	Sand & Gravel	4 ft	3.7	4.8	5.5	6.7	8.4	9.8	10.2	10.3	1.6	8.7	4.6	5.7
RN-11	Winter	5-in. Asphalt	6-in. P.C. Foamglas	Sand & Gravel	4 ft				5.3	5.9	6.1	6.4	6.4	2.3	4.1	4.3	2.1
				Effect of Pavement Surface													
RN-3	Summer	Gravel	None	Sand & Gravel	4 ft	3.3	5.9	6.8	8.1	9.1	9.6	8.1	10.0	1.8	8.2	3.3	5.7
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	4.0	6.2	7.2	8.6	9.5	10.2	10.2	10.5	1.8	8.7	4.2	6.3
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	3.5	6.1	7.3	8.8	9.7	10.3	10.0	10.4	1.4	9.0	4.4	6.0
RN-18	Summer	12-in. Concrete	None	Sand & Gravel	4 ft	3.6	5.6	6.8	8.2	9.3	10.0	10.0	10.0	2.0	8.0	4.7	5.3
RN-24	Spring	6-in. Concrete	None	Sand & Gravel	4 ft	3.5	5.8	6.8	7.9	9.7	10.4	10.3	10.3	3.4	6.9	4.6	5.7
RN-25	Spring	5-in. Asphalt	None	Sand & Gravel	4 ft	4.1	6.4	7.5	8.7	9.8	10.3	10.3	10.3	3.4	6.9	4.3	6.0
RN-26	Spring	Gravel	None	Sand & Gravel	4 ft	4.2	5.5	7.2	8.8	9.9	10.0	10.0	10.0	3.5	6.5	4.7	5.3
				Effect of Insulation													
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	4.0	6.2	7.2	8.6	9.5	10.2	10.2	10.5	1.8	8.7	4.2	6.3
RN-5	Summer	5-in. Asphalt	3-in. P.C. Foamglas	Sand & Gravel	4 ft	3.7	5.2	6.3	7.4	8.7	9.7	10.2	10.5	2.1	8.4	4.4	6.1
RN-6	Summer	5-in. Asphalt	6-in. P.C. Foamglas	Sand & Gravel	4 ft	3.7	4.8	5.5	6.7	8.4	9.8	10.2	10.3	1.6	8.7	4.6	5.7
RN-7	Summer	5-in. Asphalt	6-in. Cell Concrete (Med Den.)	Sand & Gravel	4 ft	3.9	6.0	7.8	9.1	9.8	10.2	10.4	10.4	1.5	8.9	4.2	6.2
RN-8	Summer	5-in. Asphalt	6-in. Cell Concrete (Low Den.)	Sand & Gravel	4 ft	4.0	5.7	6.8	8.1	9.6	10.2	10.4	10.4	1.7	8.7	4.4	6.0
RN-9	Summer	5-in. Asphalt	12-in. Cell Concrete (Med Den.)	Sand & Gravel	4 ft	4.4	5.8	6.8	8.0	9.3	10.2	10.4	10.6	1.8	8.8	4.2	6.4
RN-19	Summer	5-in. Asphalt	6-in. Comp Spruce Branches	Sand & Gravel	4 ft	3.6	5.8	7.4	8.8	9.8	10.2	-	10.2	2.1	8.1	4.8	5.4
RN-20	Summer	5-in. Asphalt	6-in. Comp Moss	Sand & Gravel	4 ft	3.7	5.5	6.9	8.1	9.2	10.2	10.2	10.4	2.1	8.3	4.4	6.0
RN-21	Summer	5-in. Asphalt	6-in. Zonolite Concrete	Sand & Gravel	4 ft	3.3	5.6	7.0	8.4	9.6	10.3	10.0	10.3	1.3	9.0	4.2	6.1
				Effect of Base Course													
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	4.0	6.2	7.2	8.6	9.5	10.2	10.2	10.5	1.8	8.7	4.2	6.3
RN-22	Summer	5-in. Asphalt	None	Sand	4 ft	4.0	6.1	7.5	8.7	9.9	10.3	10.5	10.5	1.5	9.0	4.8	5.7
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	3.5	6.1	7.3	8.8	9.7	10.3	10.0	10.4	1.4	9.0	4.4	6.0
RN-23	Summer	6-in. Concrete	None	Sand	4 ft	2.6	5.2	7.0	8.1	9.8	10.3	10.4	10.5	2.8	7.7	5.0	5.5

TABLE 10 (Continued)

Sec. No.	Construction Season	Surface	Insulation	Base Course Type	Base Course Design Thickness	Total Depth of Thaw -- Below Pavement Surface 1 May	1 June	1 July	1 Aug	1 Sept	1 Oct	1 Nov	Max	Height of Base Course Above Original Ground Surface	Maximum Depth of Thaw Below Original Ground Surface	Height of Base Course Above Final Subgrade	Maximum Depth of Thaw Below Final Subgrade
				Effect of Base Course Thickness													
RN-1	Summer	5-in. Asphalt	None	Sand & Gravel	12 ft	4.8	10.2	13.6	16.1	17.1	17.8	17.2	17.8	10.0	7.8	12.4	5.4
RN-14	Summer	5-in. Asphalt	None	Sand & Gravel	10 ft	5.5	9.6	11.9	13.9	15.2	15.6	15.9	16.0	8.2	7.8	10.4	5.8
RN-2	Summer	5-in. Asphalt	None	Sand & Gravel	8 ft	5.0	8.8	10.4	12.5	14.0	14.1	14.1	14.1	6.5	7.6	8.3	5.8
RN-15	Summer	5-in. Asphalt	None	Sand & Gravel	6 ft	4.6	7.8	9.4	10.3	10.6	11.0	10.9	11.0	5.0	6.0	6.5	4.5
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	4.0	6.2	7.2	8.6	9.5	10.2	10.2	10.5	1.8	8.7	4.2	6.3
RN-12	Summer	5-in. Asphalt	None	Sand & Gravel	2 ft	3.8	6.0	7.0	8.2	9.4	10.1	10.5	10.5	0.6	9.9	2.7	7.8
RN-16	Summer	6-in. Concrete	None	Sand & Gravel	6 ft	2.9	7.3	9.1	10.3	10.4	10.9	10.5	11.0	5.1	5.9	6.6	4.4
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	3.5	6.1	7.3	8.8	9.7	10.3	10.0	10.4	1.4	9.0	4.4	6.0
RN-13	Summer	6-in. Concrete	None	Sand & Gravel	2 ft	2.5	5.4	7.2	8.1	8.7	9.1	9.4	9.4	1.0	8.4	2.5	6.9
				Natural Ground													
R-201		Moss	None	None	None	-	-	3.1	3.8	4.2	4.5	4.0	4.5	0.0	4.5	0.0	4.5
R-204		Moss	None	None	None	0.0	2.2	3.5	5.2	6.0	6.0	5.8	6.0	0.0	6.0	0.0	6.0
R-202		Gravel	None	Sand & Gravel	4 ft	3.2	6.2	8.2	9.6	9.8	10.0	10.0	10.0	2.0	8.0	4.4	5.6
R-203		Gravel	None	Sand & Gravel	4 ft	3.1	6.2	7.8	9.4	9.8	10.0	10.0	10.0	2.0	8.0	4.6	5.4

TABLE 11

DEPTH OF THAW -- 1948
FAIRBANKS RESEARCH AREA NO. 2

Sec. No.	Construction Season	Surface	Insulation	Base Course Type	Base Course Design Thickness	Total Depth of Thaw -- Below Pavement Surface 1 May	1 June	1 July	1 Aug	1 Sept	1 Oct	1 Nov	Max	Height of Base Course Above Original Ground Surface	Maximum Depth of Thaw Below Original Ground Surface	Height of Base Course Above Final Subgrade	Maximum Depth of Thaw Below Final Subgrade
						Effect of Construction Season											
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	0.3	5.5	7.6	8.9	10.0	10.0	9.4	10.0	1.8	8.2	4.2	5.8
RN-25	Spring	5-in. Asphalt	None	Sand & Gravel	4 ft	0.4	6.3	7.4	9.3	*	*	*	-	3.4	-	4.3	-
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	0.4	6.3	7.6	8.5	9.2	9.5	7.4	9.6	1.4	8.2	4.4	5.2
RN-24	Spring	6-in. Concrete	None	Sand & Gravel	4 ft	0.4	6.1	7.3	8.2	9.0	8.8	8.2	9.1	3.4	5.7	4.6	4.5
RN-3	Summer	Gravel	None	Sand & Gravel	4 ft	0.0	5.5	7.0	8.6	10.4	10.9	*	11.0	1.8	9.2	4.3	6.7
RN-26	Spring	Gravel	None	Sand & Gravel	4 ft	0.2	6.0	7.8	9.2	9.5	9.2	9.3	9.6	3.5	6.1	4.7	4.9
RN-7	Summer	5-in. Asphalt	6-in. Cell Concrete (Med Den.)	Sand & Gravel	4 ft	0.3	4.9	7.3	8.8	10.6	11.1	10.2	11.1	1.5	9.6	4.2	6.9
RN-10	Winter	5-in. Asphalt	6-in. Cell Concrete (Med Den.)	Sand & Gravel	4 ft	0.7	5.1	7.4	8.9	10.1	10.4	9.9	10.4	1.9	8.5	4.6	5.8
RN-6	Summer	5-in. Asphalt	6-in. P.C. Foamglas	Sand & Gravel	4 ft	0.1	4.4	5.9	7.6	9.1	9.5	7.8	9.8	1.6	8.2	4.6	5.2
RN-11	Winter	5-in. Asphalt	6-in. P.C. Foamglas	Sand & Gravel	4 ft	0.4	5.2	6.4	7.1	7.7	7.9	0.0	7.9	2.3	5.6	4.3	3.6
						Effect of Pavement Surface											
RN-3	Summer	Gravel	None	Sand & Gravel	4 ft	0.0	5.5	7.0	8.6	10.4	10.8	*	11.0	1.8	9.2	4.1	5.7
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	0.3	5.5	7.6	8.9	10.0	10.0	9.4	10.0	1.8	8.2	4.2	5.8
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	0.4	6.3	7.6	8.5	9.2	9.5	7.4	9.6	1.4	8.2	4.4	5.2
RN-18	Summer	12-in. Concrete	None	Sand & Gravel	4 ft	1.6	5.8	7.4	8.6	9.7	9.5	7.2	9.9	2.0	7.9	4.7	5.2
RN-24	Spring	6-in. Concrete	None	Sand & Gravel	4 ft	0.4	6.1	7.3	8.2	9.0	8.8	8.2	9.1	3.4	5.7	4.6	4.5
RN-25	Spring	5-in. Asphalt	None	Sand & Gravel	4 ft	0.4	6.3	7.4	9.3	*	*	*	-	3.4	-	4.3	-
RN-26	Spring	Gravel	None	Sand & Gravel	4 ft	0.2	6.0	7.8	9.2	9.5	9.2	9.3	9.6	3.5	6.1	4.7	4.9
						Effect of Insulation											
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	0.3	5.5	7.6	8.9	10.0	10.0	9.4	10.0	1.8	8.2	4.2	5.8
RN-5	Summer	5-in. Asphalt	3-in. P.C. Foamglas	Sand & Gravel	6 ft	0.4	[illegible]	6.5	7.5	9.1	9.6	8.0	9.9	2.1	7.8	4.4	5.5
RN-6	Summer	5-in. Asphalt	6-in. P.C. Foamglas	Sand & Gravel	4 ft	0.1	4.4	5.9	7.6	9.1	9.5	7.8	9.8	1.6	8.2	4.6	5.2
RN-7	Summer	5-in. Asphalt	6-in. Cell Concrete (Med Den.)	Sand & Gravel	4 ft	0.3	4.9	7.3	8.8	10.6	11.1	10.2	11.1	1.5	9.6	4.2	6.9
RN-8	Summer	5-in. Asphalt	6-in. Cell Concrete (Low Den.)	Sand & Gravel	4 ft	0.4	5.4	7.5	8.9	10.2	10.5	10.5	10.8	1.7	9.1	4.4	6.5
RN-9	Summer	5-in. Asphalt	12-in. Cell Concrete (Med Den.)	Sand & Gravel	4 ft	0.3	4.9	6.5	7.8	9.7	10.4	9.8	10.4	1.8	8.6	4.2	6.2
RN-19	Summer	5-in. Asphalt	6-in. Comp Spruce Branches	Sand & Gravel	4 ft	1.0	5.9	7.4	8.2	9.2	9.9	9.4	9.9	2.1	7.8	4.8	5.1
RN-20	Summer	5-in. Asphalt	6-in. Comp Moss	Sand & Gravel	4 ft	0.7	5.4	7.2	8.4	9.8	10.0	8.2	10.4	2.1	8.3	4.4	6.0
RN-21	Summer	5-in. Asphalt	6-in. Zonolite Concrete	Sand & Gravel	4 ft	1.3	6.4	7.9	8.7	9.6	9.8	7.8	9.9	1.3	8.6	4.2	5.7
						Effect of Base Course											
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	0.3	5.5	7.6	8.9	10.0	10.0	9.4	10.0	1.8	8.2	4.2	5.8
RN-22	Summer	5-in. Asphalt	None	Sand	4 ft	1.0	6.1	8.3	10.9	11.3	8.6	7.7	11.4	1.5	9.9	4.8	6.6
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	0.3	6.3	7.6	8.5	9.2	9.5	7.4	9.6	1.4	8.2	4.4	5.2
RN-23	Summer	6-in. Concrete	None	Sand	4 ft	0.9	6.4	7.8	9.0	9.9	9.9	8.9	10.0	2.8	7.2	5.0	5.0

* Equipment inoperative.

TABLE 11 (Continued)

Sec. No.	Construction Season	Surface	Insulation	Base Course Type	Base Course Design Thickness	Total Depth of Thaw -- Below Pavement Surface 1 May	1 June	1 July	1 Aug	1 Sept	1 Oct	1 Nov	Max	Height of Base Course Above Original Ground Surface	Maximum Depth of Thaw Below Original Ground Surface	Height of Base Course Above Final Subgrade	Maximum Depth of Thaw Below Final Subgrade
				Effect of Base Course Thickness													
RN-1	Summer	5-in. Asphalt	None	Sand & Gravel	12 ft	0.2	8.9	13.1	15.3	18.4	18.2	17.4	18.5	10.0	8.5	12.4	6.1
RN-14	Summer	5-in. Asphalt	None	Sand & Gravel	10 ft	0.2	9.5	11.9	13.8	17.2	17.0	15.6	17.2	8.2	9.0	10.4	6.8
RN-2	Summer	5-in. Asphalt	None	Sand & Gravel	8 ft	0.1	8.6	10.5	12.5	14.8	14.9	14.6	15.3	4.5	8.3	8.3	7.0
RN-15	Summer	5-in. Asphalt	None	Sand & Gravel	6 ft	0.1	6.3	8.2	10.2	11.9	11.8	10.9	12.0	5.0	7.0	6.5	5.5
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	0.3	5.5	7.6	8.9	10.0	10.0	10.0	10.0	1.8	8.2	4.2	5.8
RN-12	Summer	5-in. Asphalt	None	Sand & Gravel	2 ft	0.3	6.0	7.4	8.5	9.9	9.8	8.5	10.0	0.6	7.4	2.7	7.3
RN-16	Summer	6-in. Concrete	None	Sand & Gravel	6 ft	1.0	7.5	9.0	10.6	11.8	11.4	10.5	11.8	5.1	6.7	6.6	5.2
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	0.4	6.3	7.6	8.5	9.2	9.5	7.4	9.6	1.4	8.2	4.4	5.2
RN-13	Summer	6-in. Concrete	None	Sand & Gravel	2 ft	0.3	4.9	6.6	8.0	8.8	8.7	7.7	8.9	1.0	7.9	2.7	6.4
				Natural Ground													
R-201		Moss	None	None	None	0.0	1.5	3.5	4.6	5.1	5.1	0.0	5.2	0.0	5.2	0.0	5.2
R-204		Moss	None	None	None	*	*	*	*	**	*	*	*	0.0	*	0.0	*
R-202		Gravel	None	Sand & Gravel	4 ft	0.2	6.8	11.2	12.1	12.3	11.6	0.0	12.3	2.0	10.3	4.4	7.9
R-203		Gravel	None	Sand & Gravel	4 ft	*	*	*	*	*	*	*	*	2.0	*	4.6	*

* Equipment Inoperative.

in Area No. 1, it can be said that the sections in Area No. 2 were generally no more effective in retarding thaw than the cleared and stripped Section C of Area No. 1. The general conclusion from the results obtained is that gravel fills with or without embedded layers of insulation are of little value in retarding thawing of frozen ground.

54. GROUNDWATER. Groundwater did not rise into the fills of Area No. 2 because of the very low capillarity of the material. This lack of water or ice is considered to be the principal reason for the rapid heat transfer through the fills. If the fills could have been kept in a saturated condition and frozen, undoubtedly thawing would not have penetrated them in all cases because of the greater heat capacity of the frozen material.

55. CORRELATION OF THEORY WITH TEST DATA. It should be emphasized that most of the runway test sections, which were about 4 ft thick, were actually constructed in such a manner that about one-half of the fill was placed below and one-half was above the original ground surface. The thicker base course sections were also constructed with about 2 ft of the fill below the original ground surface. The exposed portion of the fill was well drained and, as a result, there was very little water from which the latent heat of fusion had to be removed or replaced in the respective processes of thawing and freezing. As the latent heat of fusion of water is 79.6 cal per g or 79.6 times as great as the heat required to raise the temperature of one gram of water one degree Centigrade, the rate of heat transfer through a sand-gravel material can be slowed appreciably when the saturated zone below the groundwater table is encountered. The groundwater table at the Fairbanks Research Area was generally slightly above the upper surface of the permafrost layer during 1948. In view of the results encountered at the Fairbanks Research Area, it is evident that the moisture content of the ground is an important factor which must be considered in predicting the depth of thaw or depth of freeze at a particular locality.

56. COMPARISONS OF CALCULATED AND ACTUAL DEPTHS OF THAW. In the study of freezing or thawing of soils, it is necessary to keep in mind the fact that only the water in the soil is subject to a change of state. This change of state is accompanied by the absorption or liberation of a fixed amount of heat (latent heat of fusion) per pound of water. The amount of heat received by or removed from a unit area of ground surface during a season determines to a large extent the quantity of water in the soil which will undergo a change of state. Soils such as peat have a very high void content and water capacity per unit volume. Dense sand-gravel mixtures have a low void content and small water capacity per unit volume. Thus, for a given amount of heat, the depth of thaw is a function of the water content of the soil. However, the depth of thaw in low density soils generally does not increase appreciably with moisture content because of the compensating effect of thermal conductivity. Plate 23 indicates that the depth of thaw in peat is very nearly the same over a tremendous range in moisture content. However, the depth of thaw in dense sand or gravel varies considerably with changes in moisture content. Soils with ranges of density between peat and sand gravel also have intermediate ranges of depth of thaw. Calculations of depth of thaw have been made for various test sections in Areas Nos. 1 and 2 of the Fairbanks Research Area. These calculations have been based on the method of calculation described herein and on soils density and moisture data obtained from test pits adjacent to the sections. Comparisons of the calculated and actual depths of thaw during the 1947 season are tabulated on the following page.

Area No.	Section	Maximum Depth of Thaw in Ft Actual	Calculated
1	A	3.2	3.0
1	B	4.3	4.2
1	C	6.4	6.2
2	RN-2	15.0	[illegible]
2	RN-4	10.2	9.2
2	RN-6	10.3	9.1

The calculations summarized above are contained in Tables 7 and 12 to 16, inclusive. It may be noted that there is generally close agreement between the measured and calculated depths of thaw (the differences might be accounted for by the fact that seasonal thaw may exceed seasonal frost).

TABLE 12

COMPUTED DEPTH OF THAW
FAIRBANKS RESEARCH AREA NO. 1 -- SECTION A
SEPTEMBER 1947

Layer	Material	"b" Thickness of Layer in ft	"d" Dry Density of Soil lb/cu ft	"w" Water Content of Soil in % of Dry Wt	"L" 1.434 wd Volumetric Latent Heat of Fusion	"k" Thermal Conductivity	$R = \frac{b}{k}$ Thermal Resistance	ΣR	$\Sigma R + \frac{R_n}{2}$	I = Thawing Index $I_1 = \frac{L_1 b_1}{24} \times \frac{R_1}{2}$ $I_n = \frac{L_n b_n}{24} \times (\Sigma R + \frac{R_n}{2})$ Increment	Summation
Thawing index for 1947 based on air temperature = 3055. Corrected = 3055 × 0.37 = 1130.											
1	Peat and Silt (MH)	1.0	89.6	29.2	3752	$\frac{8.8}{12} = 0.73$	1.37	0.0	0.69	$\frac{3752 \times 1.0 \times 0.69}{24} = 108$	108
2	Silt (MH) and Peat	1.0	77.4	37.8	4195	$\frac{7.3}{12} = 0.61$	1.64	1.37	2.19	$\frac{4195 \times 1.0 \times 2.19}{24} = 383$	491
3	Silt (MH) and Peat	$x = \frac{1.0}{3.0}$	77.4	37.8	4195	$\frac{7.3}{12} = 0.61$	$\frac{x}{0.61}$	3.01	$3.01 + \frac{x}{1.22}$	$\frac{4195 \times x \times (3.01 + \frac{x}{1.22})}{24} = 639$	1130

Solving for depth x in Layer 3

$$\frac{4195}{24} \times x \times (3.01 + \frac{x}{1.22}) = 639 \qquad 175x\,(3.01 + \frac{x}{1.22}) = 639 \qquad 527x + 143.4x^2 - 639 = 0$$

$$x^2 + 3.68x - 4.46 = 0 \qquad x = \frac{-3.68 \pm \sqrt{3.68^2 + 17.84}}{2} = \frac{-3.68 \pm \sqrt{31.38}}{2} = \frac{-3.68 \pm 5.6}{2} = \frac{1.9}{2} = 1.0$$

Note: Computed depth = 3.0 ft. Actual depth - 3.2 ft.

TABLE 13

COMPUTED DEPTH OF THAW
FAIRBANKS RESEARCH AREA NO. 1 -- SECTION B
SEPTEMBER 1947

Layer	Material	"b" Thickness of Layer in ft	"d" Dry Density of Soil lb/cu ft	"w" Water Content of Soil in % of Dry Wt	"L" 1.434 wd Volumetric Latent Heat of Fusion	"k" Thermal Conductivity	$R = \frac{b}{k}$ Thermal Resistance	ΣR	$\Sigma R + \frac{R_n}{2}$	I = Thawing Index $I_1 = \frac{L_1 b_1}{24} \times \frac{R_1}{2}$ $I_n = \frac{L_n b_n}{24} \times (\Sigma R + \frac{R_n}{2})$ Increment	Summation
Thawing index for 1947 based on air temperature = 3055. Corrected = 3055 × 0.73 = 2230.											
1	Silt (MH) and Peat	1.7	87.4	32.2	4036	$\frac{8.8}{12} = 0.73$	2.33	0.0	1.17	$\frac{4036 \times 1.7 \times 1.17}{24} = 334$	334
2	Silt (MH) and Peat	1.0	80.1	38.0	4365	$\frac{7.8}{12} = 0.65$	1.54	2.33	3.10	$\frac{4365 \times 1.00 \times 3.10}{24} = 564$	898
3	Silt (MH) and Peat	0.8	85.5	36.6	4487	$\frac{8.4}{12} =$ [illegible]	[illegible]	3.87	4.44	$\frac{4487 \times 0.8 \times 4.44}{24} = 664$	1562
4	Silt (MH) and Peat	$x = \frac{0.7}{4.2}$	79.0	[illegible]	4305	$\frac{7.5}{12} = 0.63$	$\frac{x}{0.63}$	5.01	$5.01 + \frac{x}{1.26}$	$\frac{4305 \times x \times (5.01 + \frac{x}{1.26})}{24} = 668$	2230

Solving for depth x in Layer 4

$$\frac{4305}{24} \times x \times (5.01 + \frac{x}{1.26}) = 668 \qquad 179.4x\,(5.01 + \frac{x}{1.26}) = 668 \qquad 898.8x + 142.4x^2 - 668 = 0$$

$$x^2 + 6.31 - 4.69 = 0 \qquad x = \frac{-6.31 \pm \sqrt{39.82 + 18.76}}{2} = \frac{-6.31 \pm \sqrt{58.58}}{2} \qquad x = \frac{-6.31 \pm 7.65}{2} = \frac{1.34}{2} = 0.7$$

Note: Computed depth = 4.2 ft. Actual depth = 4.3 ft.

TABLE 14

COMPUTED DEPTH OF THAW
FAIRBANKS RESEARCH AREA NO. 1 -- SECTION C
SEPTEMBER 1947

Layer	Material	"b" Thickness of Layer in ft	"d" Dry Density of Soil lb/cu ft	"w" Water Content of Soil in % of Dry Wt	"L" 1.434 wd Volumetric Latent Heat of Fusion	"k" Thermal Conductivity	$R = \frac{b}{k}$ Thermal Resistance	ΣR	$\Sigma R + \frac{R_n}{2}$	I = Thawing Index $I_1 = \frac{L_1 b_1}{24} \times \frac{R_1}{2}$ $I_n = \frac{L_n b_n}{24} \times (\Sigma R + \frac{R_n}{2})$ Increment	Summation
Thawing index for 1947 based on air temperature = 3055. Corrected = 3055 × 1.22 = 3727.											
1	Silt (MH)	2.0	94.4	15.1	2044	$\frac{7.6}{12} = 0.63$	3.17	0.0	1.59	$\frac{2044 \times 2.0 \times 1.59}{24} = 271$	271
2	Silt (MH)	2.0	98.6	15.1	2135	$\frac{8.3}{12} = 0.69$	2.90	3.17	4.62	$\frac{2135 \times 2.0 \times 4.62}{24} = 822$	1093
3	Silt (MH)	1.0	93.6	18.1	2429	$\frac{8.0}{12} = 0.67$	1.50	6.07	6.82	$\frac{2429 \times 1.0 \times 6.82}{24} = 690$	1783
4	Silt (MH)	$x = \frac{1.2}{6.2}$	85.5	36.6	4487	$\frac{8.5}{12} = 0.71$	$\frac{x}{0.71}$	7.57	$7.57 + \frac{x}{1.42}$	$\frac{4487 \times x \times (7.57 + \frac{x}{1.42})}{24} = 1944$	3727

Solving for depth x in Layer 4

$\frac{4487}{24} \times x \times (7.57 + \frac{x}{1.42}) = 1944 \qquad 187x\,(7.57 + \frac{x}{1.42}) = 1944 \qquad 1416x + 131.7x^2 - 1944 = 0$

$x^2 + 10.75x - 14.76 = 0 \qquad x = \frac{-10.75 + \sqrt{10.75^2 + 59.04}}{2} = \frac{-10.75 + \sqrt{174.60}}{2} = \frac{-10.75 + 13.2}{2} = \frac{2.45}{2} = 1.2$

Note: Computed depth = 6.2 ft. Actual depth = 6.4 ft.

TABLE 15

COMPUTED DEPTH OF THAW
FAIRBANKS RESEARCH AREA NO. 2 -- SECTION RN-2
SEPTEMBER 1947

Layer	Material	"b" Thickness of Layer in ft	"d" Dry Density of Soil lb/cu ft	"w" Water Content of Soil in % of Dry Wt	"L" 1.434 wd Volumetric Latent Heat of Fusion	"k" Thermal Conductivity	$R = \frac{b}{k}$ Thermal Resistance	ΣR	$\Sigma R + \frac{R_n}{2}$	I = Thawing Index $I_1 = \frac{L_1 b_1}{24} \times \frac{R_1}{2}$ $I_n = \frac{L_n b_n}{24} \times (\Sigma R + \frac{R_n}{2})$ Increment	Summation
Thawing index for 1947 based on air temperature = 3055. Corrected = 3055 × 2.19 = 6690.											
1	Asphalt	0.4	150.0	0.0	0	$\frac{10.3}{12} = 0.85$	0.47	0.0	0.24	0	0
2	Gravel (GW)	3.6	142.5	3.0	613	$\frac{20.0}{12} = 1.67$	2.16	0.47	1.55	$\frac{613 \times 3.6 \times 1.55}{24} = 142$	142
3	Gravel (GW)	1.0	144.0	4.1	847	$\frac{23.0}{12} = 1.92$	0.52	2.63	2.89	$\frac{847 \times 1.0 \times 2.89}{24} = 102$	244
4	Gravel (GW)	3.5	138.0	2.0	396	$\frac{15.0}{12} = 1.25$	2.30	3.15	4.55	$\frac{396 \times 3.5 \times 4.55}{24} = 263$	507
5	Peat and Silt (MH)	0.5	68.8	67.8	6689	$\frac{7.0}{12} = 0.58$	0.86	5.95	6.38	$\frac{6689 \times 0.5 \times 6.38}{24} = 889$	1396
6	Silt (MH) and Peat	2.0	100.5	26.4	3805	$\frac{10.3}{12} = 0.85$	2.35	6.81	7.98	$\frac{3805 \times 2.0 \times 7.98}{24} = 2530$	3926
7	Silt (MH)	1.0	70.8	44.1	4477	$\frac{6.6}{12} = 0.55$	1.82	9.16	10.07	$\frac{4477 \times 1.0 \times 10.07}{24} = 1878$	5804
8	Silt (MH)	$x = \frac{0.4}{12.4}$	70.8	44.1	4477	$\frac{6.6}{12} = 0.55$	$\frac{x}{0.55}$	10.98	$10.98 + \frac{x}{1.10}$	$\frac{4477 \times x \times (10.98 + \frac{x}{1.10})}{24} = 886$	6690

Solving for depth x in Layer 8

$$\frac{4477}{24} \times x \times (10.98 + \frac{x}{1.10}) = 886 \qquad 186.5x\,(10.98 + \frac{x}{1.10}) - 886 = 0 \qquad 2047x + 169.5x^2 - 886 = 0$$

$$x^2 + 12.1x - 5.23 = 0 \qquad x = \frac{-12.1 \pm \sqrt{12.1^2 + 20.92}}{2} = \frac{-12.1 \pm \sqrt{167.3}}{2} = \frac{-12.1 \pm 12.9}{2} = 0.4$$

Note: Computed depth = 12.4 ft. Actual depth = 15.0 ft.

TABLE 16

COMPUTED DEPTH OF THAW
FAIRBANKS RESEARCH AREA NO. 2 -- SECTION RN-6
SEPTEMB R 1947

Layer	Material	"b" Thickness of Layer in ft	"d" Dry Density of Soil lb/cu ft	"w" Water Content of Soil in % of Dry Wt	"L" 1.434 wd Volumetric Latent Heat of Fusion	"k" Thermal Conductivity	$R = \frac{b}{k}$ Thermal Resistance	ΣR	$\Sigma R + \frac{R_n}{2}$	I = Thawing Index $I_1 = \frac{L_1 b_1}{24} \times \frac{R_1}{2}$ $I_n = \frac{L_n b_n}{24} \times (\Sigma R + \frac{R_n}{2})$ Increment	Summation
Thawing index for 1947 based on air temperature = 3055. Corrected = 3055 × 2.19 = 6690.											
1	Asphalt	0.4	150.0	0.0	0	$\frac{10.3}{12} = 0.86$	0.47	0.0	0.24	0	0
2	Gravel (GW)	2.0	140.0	3.4	683	$\frac{19.0}{12} = 1.58$	1.26	0.47	1.10	$\frac{683 \times 2.0 \times 1.10}{24} = 63$	63
3	P.C. Foamglas	0.5		0.0	0	$\frac{2.6}{12} = .22$	2.27	1.73	2.86	0	63
4	Gravel (GW)	1.5	142.0	3.1	631	$\frac{20.0}{12} = 1.67$	0.90	4.00	4.45	$\frac{631 \times 1.5 \times 4.45}{24} = 175$	238
5	Silt	3.5	90.0	30.4	3923	$\frac{9.0}{12} = 0.75$	4.67	4.90	7.24	$\frac{3923 \times 3.5 \times 7.24}{24} = 4142$	4380
6	Silt & Peat	$x = \frac{1.2}{9.1}$	80.0	41.0	4704	$\frac{7.8}{12} = 0.65$	$\frac{x}{0.65}$	9.57	$9.57 + \frac{x}{1.30}$	$\frac{4704 \times x \times (9.57 + \frac{x}{1.30})}{24} = 2310$	6690

Solving for depth x in Layer 6

$$\frac{4704}{24} \times x \times (9.57 + \frac{x}{1.30}) = 2310 \qquad 196x\,(9.57 + \frac{x}{1.30}) = 2310 \qquad 1875x + 150.8x^2 - 2310 = 0$$

$$x^2 + 12.4x - 15.3 = 0 \qquad x = \frac{-12.4 + \sqrt{153.8 + 61.2}}{2} = \frac{-12.4 + \sqrt{216}}{2} \qquad x = \frac{-12.4 + 14.7}{2} = \frac{2.3}{2} = 1.2 \text{ ft}$$

Note: Computed depth = 9.1 ft. Actual depth = 10.3 ft.

57. VERTICAL MOVEMENT OF GROUND AND TEST SECTION SURFACES. Table 17 summarizes the range of average annual vertical movement, the range of maximum vertical movement at any one point, and the range of maximum differential movement between any two points in the test sections of Area No. 2 for the period November 1946 through October 1947 and from November 1947 to October 1948. The data indicate that the range of vertical movement is greatest for sections constructed during the summer and least for those constructed during the winter. No definite indication is given that any surface or type of insulation is more suitable than the others tested. Of the few sections

TABLE 17

SUMMARY OF VARIOUS CONSTRUCTION FEATURES AND ANNUAL VERTICAL MOVEMENTS
FAIRBANKS RESEARCH AREA NO. 2 -- 1947 AND 1948

Sec. No.	Construction Season	Surface	Insulation	Type	Design Thickness	Range of Average Annual Vertical Movement: Nov 1946-Oct 1947	Range of Average Annual Vertical Movement: Nov 1947-Oct 1948	Range of Max Vertical Movement At Any One Point: Nov 1946-Oct 1947	Range of Max Vertical Movement At Any One Point: Nov 1947-Oct 1948	Range of Max Differential Movement Between Any 2 Pts in ft/100 ft: Nov 1946-Oct 1947	Range of Max Differential Movement Between Any 2 Pts in ft/100 ft: Nov 1947-Oct 1948
Effect of Construction Season											
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	-	0.202 ft	-	0.221 ft	-	0.094
RN-25	Spring	5-in. Asphalt	None	Sand & Gravel	4 ft	0.169 ft	0.138 ft	0.194 ft	0.157 ft	0.287	0.277
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	0.186 ft	0.171 ft	0.213 ft	0.204 ft	0.319	0.257
RN-24	Spring	6-in. Concrete	None	Sand & Gravel	4 ft	0.165 ft	0.152 ft	0.163 ft	0.218 ft	0.152	0.320
RN-3	Summer	Gravel	None	Sand & Gravel	4 ft	0.183 ft	0.176 ft	0.239 ft	0.199 ft	0.377	0.376
RN-26	Spring	Gravel	None	Sand & Gravel	4 ft	0.180 ft	0.117 ft	0.252 ft	0.132 ft	0.461	0.536
RN-7	Summer	5-in. Asphalt	6-in. Cell Concrete M.D.	Sand & Gravel	4 ft	-	0.208 ft	-	0.211 ft	-	0.094
RN-10	Winter	5-in. Asphalt	6-in. Cell Concrete M.D.	Sand & Gravel	4 ft	-	0.093 ft	-	0.104 ft	-	0.130
RN-6	Summer	5-in. Asphalt	6-in. P.C. Foamglas	Sand & Gravel	4 ft	-	0.140 ft	-	0.165 ft	-	0.198
RN-11	Winter	5-in. Asphalt	6-in. P.C. Foamglas	Sand & Gravel	4 ft	-	0.111 ft	-	0.111 ft	-	0.330
Effect of Surface											
RN-3	Summer	Gravel	None	Sand & Gravel	4 ft	0.183 ft	0.176 ft	0.239 ft	0.199 ft	0.377	0.376
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	-	0.202 ft	-	0.221 ft	-	0.094
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	0.186 ft	0.171 ft	0.213 ft	0.204 ft	0.319	0.257
RN-18	Summer	12-in. Concrete	None	Sand & Gravel	4 ft	0.205 ft	0.189 ft	0.235 ft	0.218 ft	0.122	0.188
RN-24	Spring	6-in. Concrete	None	Sand & Gravel	4 ft	0.165 ft	0.152 ft	0.183 ft	0.218 ft	0.152	0.320
RN-25	Spring	5-in. Asphalt	None	Sand & Gravel	4 ft	0.179 ft	0.138 ft	0.194 ft	0.157 ft	0.287	0.277
RN-26	Spring	Gravel	None	Sand & Gravel	4 ft	0.180 ft	0.117 ft	0.252 ft	0.132 ft	0.461	0.536
Effect of Insulation											
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	-	0.202 ft	-	0.221 ft	-	0.094
RN-5	Summer	5-in. Asphalt	3-in. P.C. Foamglas	Sand & Gravel	4 ft	-	0.122 ft	-	0.133 ft	-	0.639
RN-6	Summer	5-in. Asphalt	6-in. P.C. Foamglas	Sand & Gravel	4 ft	-	0.140 ft	-	0.165 ft	-	0.198
RN-7	Summer	5-in. Asphalt	6-in. Cell Concrete M.D.	Sand & Gravel	4 ft	-	0.208 ft	-	0.211 ft	-	0.094
RN-8	Summer	5-in. Asphalt	6-in. Cell Concrete L.D.	Sand & Gravel	4 ft	-	0.165 ft	-	0.203 ft	-	0.190
RN-9	Summer	5-in. Asphalt	12-in. Cell Concrete M.D.	Sand & Gravel	4 ft	-	0.088 ft	-	0.108 ft	-	0.122
RN-19	Summer	5-in. Asphalt	6-in. Comp Spruce	Sand & Gravel	4 ft	-	0.143 ft	-	0.155 ft	-	0.132
RN-20	Summer	5-in. Asphalt	6-in. Comp Moss	Sand & Gravel	4 ft	-	0.172 ft	-	0.197 ft	-	0.306
RN-21	Summer	5-in. Asphalt	6-in. Zonolite Concrete	Sand & Gravel	4 ft	-	0.183 ft	-	0.192 ft	-	0.687
Effect of Base Course											
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	-	0.202 ft	-	0.221 ft	-	0.094
RN-22	Summer	5-in. Asphalt	None	Sand	4 ft	-	0.161 ft	-	0.185 ft	-	0.470
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	0.186 ft	0.171 ft	0.213 ft	0.204 ft	0.319	0.257
RN-23	Summer	6-in. Concrete	None	Sand	4 ft	0.171 ft	0.140 ft	0.178 ft	0.157 ft	0.104	0.146
Effect of Base Course Thickness											
RN-1	Summer	5-in. Asphalt	None	Sand & Gravel	12 ft	0.080 ft	0.076 ft	0.119 ft	0.103 ft	0.409	0.273
RN-14	Summer	5-in. Asphalt	None	Sand & Gravel	10 ft	0.094 ft	0.060 ft	0.151 ft	0.089 ft	0.234	0.305
RN-2	Summer	5-in. Asphalt	None	Sand & Gravel	8 ft	0.111 ft	0.0[illegible]3 ft	0.145 ft	0.093 ft	0.248	0.555
RN-15	Summer	5-in. Asphalt	None	Sand & Gravel	6 ft	0.140 ft	0.108 ft	0.166 ft	0.119 ft	0.193	0.240
RN-4	Summer	5-in. Asphalt	None	Sand & Gravel	4 ft	-	0.202 ft	-	0.221 ft	-	0.094
RN-12	Summer	5-in. Asphalt	None	Sand & Gravel	2 ft	0.102 ft	0.194 ft	0.236 ft	0.210 ft	0.381	0.617
RN-16	Summer	6-in. Concrete	None	Sand & Gravel	6 ft	0.131 ft	0.038 ft	0.147 ft	0.104 ft	0.136	0.151
RN-17	Summer	6-in. Concrete	None	Sand & Gravel	4 ft	0.185 ft	0.171 ft	0.213 ft	0.204 ft	0.319	0.257
RN-13	Summer	6-in. Concrete	None	Sand & Gravel	2 ft	0.248 ft	0.236 ft	0.280 ft	0.275 ft	0.280	0.340
Control Points						0.448 ft	0.363 ft	0.493 ft	0.389 ft	0.019	0.032
R-101								0.424 ft	0.383 ft		
R-102								0.428 ft	0.334 ft		
R-103								0.493 ft	0.365 ft		

tested, it appears that a sand base course is slightly better than a sand and gravel base course. In general, the thicker the base courses, the less was the vertical movement of the section. The differential movement between different points in a test section appears to be largest in unsurfaced sections, smallest in concrete paved sections, and intermediate in asphalt-surfaced sections. The latter condition reflects the relative rigidities of the three types of surfacing.

Area No. 3 -- Fairbanks Research Area

58. PURPOSE. Area No. 3 of the Fairbanks Research Area was constructed with a view to determining the effect of various types of foundation construction on heat transfer. Eight 16-ft-square, frame buildings were constructed in this area in 1946, and observations have been made since that time of ground temperatures, settlement, and groundwater conditions in the vicinity.

59. GROUND TEMPERATURES. Summaries of the depth of thaw below the top of fill or ground surface under each building, at monthly intervals from May to November in 1947 and 1948, are shown in Tables 18 and 19, respectively. The greatest depth of thaw during both 1947 and 1948 occurred under Building 1. The ground under the center of this building did not refreeze during the winter and the depth of thaw advanced progressively during 1948 from 12.0 ft to 13.6 ft. Building 11 had the next greatest depth of thaw, namely, 13.0 ft under the center in 1948. Refreezing did not occur at this point during the winter. The concrete floor of Building 1 and the composite hollow tile and concrete floor of Building 11, both of which were placed directly on the ground, were the most effective in conducting heat into the ground. A future experimental study might include the effect of forcing cold air through the hollow tile during the winter. It is evident that gravity flow of air through the small openings in the tile is insufficient to dissipate heat from the building before it can pass into the ground. The ground under the center of Building 2 did not freeze during the winter of 1947-1948 probably as a result of a stoppage of air circulation under the floor due to snow accumulation adjacent to the walls. Building 3, constructed on a 2-ft fill, had less depth of thaw than any of the buildings constructed on 4-ft or 6-ft fills. Building 4, in which the floor insulation had been removed, had about the same maximum depth of thaw in both 1947 and 1948, namely, 10.8 and 11.0 ft. Ground under this building froze during the winter. Building 5 was constructed with a 6-in. cell concrete insulation layer in the 4-ft sand and gravel fill. Results obtained, when compared with Building 2, indicate only a small benefit from the insulation. None of the designs using fills, including the fill with an insulation layer (Building 5), were as effective in preventing heat transfer into the ground as the design for Building 8 where mud sills were placed directly on the natural ground. The most effective design types were those using posts or pile foundations which provided a 2-ft or larger air space between the floor and the ground for free air circulation. During the period of record, less depth of thaw was observed under Buildings 6, 7, 8 and 10 than in the natural ground in the vicinity of temperature holes B-101, B-103 and B-104. In Building 7 where skirting prevented free air movement, the depth of thaw was greater than for Building 6 where skirting was not used. Building 9, supported by concrete spread footings with a 3-ft air space between the footing and the floor, provided by concrete struts, was not as effective as Building 10, supported on wood piles, in preventing heat transfer.

60. MOISTURE CONTENT OF SOILS. Periodic determinations of soil moisture were made under Buildings 1 to 11, inclusive, in Area No. 3. Generally, the moisture content of gravel fills was much less than in the natural subgrade. Relatively large variations

TABLE 18

DEPTH OF THAW -- 1947
FAIRBANKS RESEARCH AREA NO. 3

Building No.	Floor Type	Floor Insulation	Foundation Material	Foundation Design Thickness	Insulation in Fill	Total Depth of Thaw Below Top of Fill or Ground Surface: 1 May	1 June	1 July	1 Aug	1 Sept	1 Oct	1 Nov	Max	Height of Fill Above Original Ground Surface	Max Depth of Thaw Below Original Ground Surface	Height of Fill Above Final Subgrade	Max Depth of Thaw Below Final Subgrade
1	Concrete	None	Sand & Gravel Fill	4 ft	None	9.8 ft	10.0 ft	10.2 ft	10.8 ft	11.5 ft	11.9 ft	12.0 ft	12.0 ft	2.0 ft	10.0 ft	4.0 ft	8.0 ft
2	Wood	Rockwool	Sand & Gravel Fill	4 ft	None	3.5 ft	5.3 ft	6.5 ft	8.0 ft	8.8 ft	9.2 ft	8.8 ft	9.2 ft	1.6 ft	7.6 ft	4.0 ft	5.2 ft
3	Wood	Rockwool	Sand & Gravel Fill	2 ft	None	1.0 ft	3.3 ft	4.7 ft	5.1 ft	5.4 ft	5.6 ft	0.0 ft	5.6 ft	0.0 ft	5.5 ft	2.5 ft	3.1 ft
4	Wood	None	Sand & Gravel Fill	6 ft	None	4.4 ft	6.5 ft	7.6 ft	8.6 ft	9.5 ft	10.3 ft	10.8 ft	10.8 ft	3.1 ft	7.7 ft	6.0 ft	4.8 ft
5	Wood	Rockwool	Sand & Gravel Fill	4 ft	6-in. Cell Concrete	2.5 ft	4.0 ft	6.2 ft	6.8 ft	6.9 ft	7.4 ft	7.0 ft	7.4 ft	2.0 ft	5.4 ft	4.0 ft	3.4 ft
6	Wood	Rockwool	Posts & Pads	Beams 2 ft above grd, no skirting	None	0.0 ft	1.5 ft	2.3 ft	2.8 ft	3.1 ft	3.3 ft	0.0 ft	3.3 ft	-	3.3 ft	-	3.3 ft
7	Wood	Rockwool	Posts & Pads	Beams 2 ft above grd, with skirting	None	0.2 ft	2.0 ft	3.3 ft	4.0 ft	4.0 ft	4.1 ft	0.0 ft	4.1 ft	-	4.1 ft	-	4.1 ft
8	Wood	Rockwool	Mud Sills	On natural ground	None	0.0 ft	1.5 ft	2.6 ft	3.2 ft	4.0 ft	4.1 ft	0.0 ft	4.1 ft	-	4.1 ft	-	4.1 ft

Note: Observations under buildings made at center of building.

Natural Ground Observation Points

Point	1 May	1 June	1 July	1 Aug	1 Sept	1 Oct	1 Nov	Max	Max Depth of Thaw Below Original Ground Surface
B-101 (South)	0.0 ft	1.3 ft	2.5 ft	3.5 ft	4.0 ft	4.4 ft	0.0 ft	4.4 ft	4.4 ft
B-103 (Center)	0.0 ft	1.3 ft	3.5 ft	4.5 ft	4.8 ft	4.6 ft	0.0 ft	4.8 ft	4.8 ft
B-104 (North)	0.8 ft	2.0 ft	3.7 ft	4.3 ft	4.7 ft	5.6 ft	0.0 ft	5.6 ft	5.6 ft
Average	0.3 ft	1.5 ft	3.2 ft	4.1 ft	4.5 ft	4.9 ft	0.0 ft	4.9 ft	4.9 ft

TABLE 19

DEPTH OF THAW -- 1948
FAIRBANKS RESEARCH AREA NO. 3

Building No.	Floor Type	Floor Insulation	Foundation Material	Foundation Design Thickness	Insulation in Fill	Total Depth of Thaw Below Top of Fill or Ground Surface: 1 May	1 June	1 July	1 Aug	1 Sept	1 Oct	1 Nov	Max.	Height of Fill Above Original Ground Surface	Max Depth of Thaw Below Original Ground Surface	Height of Fill Above Final Subgrade	Max Depth of Thaw Below Final Subgrade
1	Concrete	None	Sand & Gravel	4 ft	None	13.4 ft	13.4 ft	13.1 ft	12.8 ft	13.1 ft	13.3 ft	11.9 ft	13.6 ft	2.0 ft	11.6 ft	4.0 ft	9.6 ft
2	Wood	Rockwool	Sand & Gravel	4 ft	None	9.1 ft	9.8 ft	10.2 ft	10.5 ft	11.0 ft	10.8 ft	10.0 ft	11.0 ft	1.6 ft	9.4 ft	4.0 ft	7.0 ft
3	Wood	Rockwool	Sand & Gravel	2 ft	None	0.4 ft	3.1 ft	4.5 ft	5.5 ft	6.5 ft	6.7 ft	5.8 ft	6.7 ft	0.0 ft	6.7 ft	2.5 ft	4.2 ft
4	Wood	None	Sand & Gravel	6 ft	None	1.2 ft	6.7 ft	7.2 ft	9.7 ft	10.8 ft	10.8 ft	10.3 ft	11.0 ft	3.1 ft	7.9 ft	6.0 ft	5.0 ft
5	Wood	Rockwool	Sand & Gravel	4 ft	6-in. Cell Concrete	0.0 ft	4.6 ft	6.0 ft	6.7 ft	7.5 ft	8.4 ft	8.3 ft	8.5 ft	2.0 ft	6.5 ft	4.5 ft	4.0 ft
6	Wood	Rockwool	Posts & Pads	Beams 2 ft above grd, no skirting	None	0.3 ft	1.2 ft	2.4 ft	3.8 ft	3.8 ft	3.5 ft	0.0 ft	4.0 ft	-	4.0 ft	-	4.0 ft
7	Wood	Rockwool	Posts & Pads	Beams 2 ft above grd, with skirting	None	0.2 ft	2.3 ft	3.0 ft	4.2 ft	5.1 ft	5.3 ft	0.0 ft	5.3 ft	-	5.3 ft	-	5.3 ft
8	Wood	Rockwool	Mud Sills	On natural grd	None	0.4 ft	1.6 ft	2.2 ft	2.8 ft	3.9 ft	4.4 ft	0.0 ft	4.4 ft	-	4.4 ft	-	4.4 ft
9	Insulated Wood over Concrete	Rockwool	Concrete Slab	3-in. Air space	None	*	*	8.5 ft	9.1 ft	10.2 ft	10.5 ft	0.0 ft	10.6 ft	2.0 ft	8.6 ft	6.0 ft	4.6 ft
10	Insulated Wood	Rockwool	Wood Piles	5-in. Air space	None	0.0 ft	1.4 ft	2.3 ft	3.2 ft	4.2 ft	4.6 ft	4.6 ft	4.8 ft	-	4.8 ft	-	4.8 ft
11	Concrete	None	Tile & Concrete Slab	3-in. Air space	None	12.0 ft	12.0 ft	12.0 ft	12.0 ft	12.8 ft	13.0 ft	13.0 ft	13.0 ft	1.0 ft	12.0 ft	5.0 ft	8.0 ft
Natural Ground Observation Points																	
B-101 (South)						0.2 ft	2.0 ft	2.8 ft	4.1 ft	4.9 ft	4.9 ft	0.0 ft	5.1 ft		5.1 ft		
B-103 (Center)						0.0 ft	1.0 ft	3.8 ft	5.8 ft	6.0 ft	5.7 ft	2.8 ft	6.0 ft		6.0 ft		
B-104 (North)						0.0 ft	0.9 ft	4.0 ft	5.8 ft	6.5 ft	5.9 ft	0.0 ft	6.5 ft		6.5 ft		
Average						0.1 ft	0.7 ft	3.5 ft	5.2 ft	5.8 ft	5.5 ft	0.9 ft	5.9 ft		5.9 ft		

Note: Observations under building made at center of building.
* Records missing.

in moisture were noted for the various observations. Peat layers interspersed between the silt layers at greater depths contained very high moisture contents which is a normal condition for such material.

61. VERTICAL MOVEMENT OF GROUND SURFACE AND TEST STRUCTURES. Vertical movement data pertinent to control points on the ground surface, and test buildings and piling in Area No. 3 are shown in Plates 33 to 38, inclusive. Variations in the average vertical movement of buildings from the elevations at the start of observations are shown in Plates 35 and 36. With the exception of Building 1, movement of the buildings is cyclical with the seasons and only a small amount was residual after 2 years of observations. Building 1, which was constructed on a concrete floor placed on a 4-ft gravel fill, has had quite uniform and progressive settlement. The greatest range of vertical movement occurred in Buildings 6, 7 and 8 which were placed on natural ground. The vertical movement of buildings placed on gravel fills was less than on natural ground and appears to be a function of the thickness of the gravel fill. Plate 39 indicates that 6 ft may be the optimum thickness of foundation fill required for small buildings under conditions similar to those prevailing during the test. Data concerning the vertical movement of the test piles in Area No. 3 are shown in Plates 37 and 38. It may be noted that piling with penetrations into permafrost less than twice the thickness of the active layer had vertical movements (heaving) appreciably greater in 1947-1948 than was the case for ratios of penetration equal to or greater than two. Data for the winter of 1946-1947 were not obtained until January 1947 at which time most of the heaving had already taken place. It appears that for stability, a ratio of 3 should be used in construction under conditions similar to those prevailing during the test. Vertical movements of control points placed on the natural ground in building and piling areas are shown in Plates 33 and 34. Movements of the control points were several times larger than the buildings and piling, indicating that the piling resisted most of the movement in the active layer. Results obtained from the swellometer tests, as shown in Plates 40, 41 and 42, confirmed the above conditions. It may be noted that swellometers 1 and 13 indicated soil heaving principally in the upper 2 ft while swellometer 25 showed movement to a depth of 5 ft. However, the maximum movement of soil at swellometer 13, about 0.28 ft, was shown to be twice as great as at swellometer 25. The soil in this general area is stratified silt and peat which is especially susceptible to frost action. Steps on Buildings 9 and 10 were displaced at the lower end due to heaving of the ground. It appears that steps should not be supported on frost-susceptible ground but rather hinged or cantilevered at the upper end. A septic tank constructed to treat domestic sewage from Buildings 9, 10 and 11 collapsed after less than one year of use due to melting of permafrost in the adjacent ground. This septic tank was constructed of wood and was placed entirely below the ground surface.

62. REFREEZING OF TIMBER PILING PLACED AFTER STEAM THAWING OF GROUND. In connection with the construction of Test Building 10 in Area No. 3, observations were made to determine the rate at which the thawed ground may be expected to refreeze around piling placed in a hole thawed into permafrost with steam jets. For this purpose, thermocouple strings were placed adjacent to one pile at the midpoint of the north side of the building and to one pile at the southeast corner of the building. In placing each pile, a hole approximately 3 ft in diameter was excavated by hand through the thawed surface layer which, at the time of installation (late July 1947), was about 4 ft thick. A hole of sufficient size and depth to receive the pile was then formed in the frozen silt by steam jetting. The thawed silt or muck was left in the hole and the pile was placed butt down in the hole to a depth of 20 ft 6 in. and seated with several light blows by a drop hammer. Prior to backfilling, a 1-1/4-in. pipe reaching from the ground surface to a depth of 21 ft was placed adjacent to the pile to receive the thermocouple string.

Thermocouple strings were placed in the pipe adjacent to the north pile on 22 July 1947 and adjacent to the southeast pile on 28 July 1947 immediately subsequent to the placing of the piles. Although the lower portions of the two piles were frozen in within a few days after placement and the top portions froze in during the winter, it is not evident that the center portions were refrozen when observations were discontinued in January 1948. Observations will be resumed in 1949 to determine existing temperature conditions. Since the temperature of the permafrost is only slightly below freezing, it is apparent that the refreezing of the piles was slowed up by the heat introduced by the steam thawing. In similar situations where the permafrost temperature is near the freezing point, it is suggested that the holes for the piling be drilled, thus reducing the amount of heat introduced into the pile hole. The length of piling should also be increased to give a penetration into the permafrost greater than twice the thickness of the active zone.

63. CORRELATION OF THEORY WITH TEST DATA. The least depth of thaw occurred under buildings placed on posts or mud sills above the natural ground where fills were not used. The construction in which no skirting was used around the posts was more effective than where skirting was used, probably because the latter was not opened during the winter season. Mud sill construction was in effect very similar to the skirted construction, although the air space between floor and ground was less. It appears that the greater depth of thaw under buildings placed on fills than under those placed on natural ground is due to the greater density and diffusivity of the compacted sand-gravel fill than that of the natural ground. Plates 43 and 44 show a comparison of the depth of thaw in and under various thicknesses of fill during 1947 and 1948 under both runway and building structures. The depths of thaw where no fills were used are also shown. It may be noted that the depths of thaw were essentially the same whether buildings or runway pavements were placed on a given fill thickness. A similar condition may be noted for unfilled areas and natural areas on which buildings were placed. Calculations of depth of thaw under the various buildings in Area No. 3 were not made because vital information concerning density and moisture of the soil could not be obtained after construction; the floor of only one building was placed directly on the ground, and edge effects were apparently very large in the small buildings tested. A calculation of the depth of thaw under the hangar building at Northway Airfield, Alaska was presented in Section VIII.

64. USE OF AIR SPACE UNDER STRUCTURES. The general conclusion from the tests is that the most desirable foundation design to prevent heat transfer into the ground is one with wood piling anchored in permafrost and providing an air space between the ground and building floor for circulation of cold air during the winter. Skirting should be provided for closing the air space and preventing circulation during the summertime under conditions where no artificial heat is used in the building. The air space dissipates heat from the building and causes normal deep freezing of the ground during the wintertime, thus preventing deterioration of the permafrost which supports the piling. The action of the skirting during the summer is to prevent warm air circulation under the building which would tend to raise the ground temperature. For best results, skirting should be removed during the winter to permit air circulation.

X Conclusions

65. GENERAL. These conclusions are based on observations in areas south of the Brooks Range in Alaska where the mean annual temperature is between 20° and 30° F.

Airfield site studies

66. SITE SELECTION. Site selection in arctic and subarctic regions is more important than in temperate zones and, wherever possible, structures should be located on coarse-grained, non-frost-heaving materials where the lowering of the permafrost surface will not cause damage to the structure.

67. STABLE STRUCTURES. Stable structures and runways can be built on non-frost-heaving materials available in arctic and subarctic regions using design and construction procedures commonly employed in temperate zones.

68. STABLE VERTICAL CONTROL POINTS. In general, stable vertical control points or bench marks may be obtained by placing pipe to a depth in the permafrost equal to at least twice the thickness of the active zone. In placing a vertical control point, care must be taken to avoid areas where the permafrost layer may be affected by heated structures or utilities. (See paragraph 7, Appendix I.)

Construction operations

69. HEAVY EQUIPMENT. The heavier types of construction equipment are the most effective in arctic and subarctic construction operations if properly winterized.

70. STANDARDIZATION OF EQUIPMENT. The necessity of continuous operation of construction equipment during all weather conditions, plus the isolation and remoteness from suppliers, requires the use of standardized equipment with a maximum of interchangeable parts and also requires an ample supply of spare parts.

Meteorological data studies

71. SCOPE OF DATA. Additional data must be collected in order to correlate the effects of climatic factors, soil characteristics, and ground temperatures.

Thermal properties of soils and insulating materials

72. THERMAL CONDUCTIVITY OF SOILS. The coefficient of thermal conductivity of soil varies as follows (see paragraph 16):

a. Above freezing, it increases slightly with an increase in mean temperature.

b. Below freezing, for soils at low moisture contents, it shows very little change; for greater moisture contents, it shows an increase for a decrease in temperature.

c. For a change from unfrozen to frozen soil, it changes variably according to the moisture content. For dry soils it does not change; for soils of low moisture content, it decreases; and for soils of high moisture content, it increases.

d. At a constant moisture content, it increases with an increase in dry density.

The rate of increase is about the same at all moisture contents and is not markedly different for frozen and unfrozen soils.

e. At a constant dry density, it increases with an increase in moisture content.

f. For saturated, unfrozen soils, it decreases with a decrease in density. For saturated, frozen soils, the data indicate no well-defined relationship between density and conductivity.

g. It varies in general with the texture of the soil, being high for gravels and sands, lower for the sandy loams, and lowest for the silt and clay soils.

h. It differs appreciably for different soil minerals. Quartz has greater conductivity than plagioclase feldspar and pyroxene.

i. Angular soil particles have from 20 to 50 percent greater conductivity than rounded soil particles.

73. SPECIFIC HEAT OF SOILS. The specific heats of soils are all approximately the same and vary in proportion to the temperature.

74. THERMAL CONDUCTIVITY OF LIGHTWEIGHT CONCRETE. The coefficient of thermal conductivity of lightweight concrete slabs was found to vary directly according to their densities.

Aerial photographic reconnaissance

75. PRELIMINARY SITE SELECTION. In the hands of a trained observer, the study of aerial photographs will greatly assist in preliminary site selection by eliminating the poor soil areas and by selecting the good sites, thus concentrating the field investigation on those areas best suited to construction and the over-all tactical and logistical situation.

76. PLANNING OPERATIONS. In a military sense, this method has particular application in planning operations in a territory held by hostile forces. Possession of adequate photography will permit advance planning of airfields and structures with the certainty that the least desirable locations are avoided and adequate construction areas are utilized.

77. SIMILARITIES. Similar land areas under similar climatic conditions can be expected to have similar photographic patterns.

Geophysical exploration methods

78. GEOPHYSICAL EXPLORATION METHODS. The results so far obtained are not sufficiently encouraging to justify further efforts until improved electrical resistivity methods are developed.

Library research

79. LIBRARY RESEARCH. The contract with the Stefansson Library has provided

a search by competent translators of Russian literature which may be pertinent to the Permafrost Investigation. The brief summaries and translations of the Russian literature, available at this time, have confirmed many of the ideas and theories developed in the study of permafrost. Although no new fundamental concept of the problem has been discovered, the many angles of approach and statements obtained from articles in Russian, Scandinavian and English literature have helped to clarify and expand the understanding of the subject.

Runways and access roads

80. PENETRATION OF ANNUAL THAW. The depth of annual thaw penetration and the average depth to permafrost at Northway in the sand subgrade under the runway have stabilized at a depth of 10 ft. (See paragraph 8h, Appendix I.) This depth is essentially the same as that calculated for a saturated, medium density condition for Northway sand. (See Plate 23.) The calculated depth of thaw in saturated, high density Fairbanks gravel is about 21 ft. Thawing penetrated a 12-ft gravel base course composed of unsaturated high density Fairbanks gravel (the thickest section tested) plus 6 ft of saturated, medium density Fairbanks silt loam at the Research Area. Results of calculations based on data from field and laboratory tests made in connection with this investigation (Plate 23) indicate that depth of thaw is greater in coarse-grained material (sand and gravel) than in fine-grained material (silt or peat). North of the Brooks Range, lesser depths of seasonal thaw may be expected than at Fairbanks.

81. TEMPERATURE CRACKS. Temperature cracks in gravel as well as in bituminous pavements will develop during the freezing season even though the base course consists of non-heaving materials.

82. INSULATING EFFECT OF NATURAL VEGETATIVE COVER. Less thawing occurs under natural vegetative cover than where the cover has been partially or entirely removed. The deepest thawing occurs where the cover has been entirely removed. (See Table 6.)

83. COLDER GROUND TEMPERATURES UNDER NATURAL VEGETATIVE COVER. Colder ground temperatures occur where the natural vegetative cover is left in place than where removed because the ground freezes solid earlier in the season since there is less thawed material to refreeze and since frozen ground is a better thermal conductor than unfrozen ground. (See paragraph 50.)

84. CONSTRUCTION SEASONS VERSUS SUBGRADE THERMAL EFFECTS. Presently available data do not indicate any substantial advantage of construction in one season over another as far as subgrade thermal effects are concerned. (See paragraph 53.)

85. UNIFORMITY OF DEPTH OF THAW. The depth of thaw was the same for all types of pavement tested. (See paragraph 53.)

86. EFFECTIVENESS OF INSULATING MATERIALS IN BASE COURSES. Insulating materials in base courses are not effective in preventing thaw under runways. (See paragraph 53.)

87. SIMILARITIES IN DEPTHS OF THAW. At the end of the summer thawing season, the depth of thaw in the sections tested was the same whether the base course was composed of sand or of sand and gravel. (See paragraph 53.)

88. EFFECTIVENESS OF SAND AND GRAVEL BASE COURSES AS INSULATORS. Sand and gravel base courses or fills are not particularly effective as insulators in preventing heat transfer into the subgrade. (See Plate 23.) Tests at the Fairbanks Research Area indicate no substantial reduction in thawing in the natural subgrade (fine-grained soil) under sand and gravel fills from 2 ft to 12 ft thick as compared with the stripped subgrade without a fill. (See paragraph 53.)

89. HEAT TRANSFER IN A RUNWAY BASE COURSE. Heat transfer in a runway base course depends, among other factors, on the density and moisture content of the material of which it is composed as well as the available heat energy of the surrounding natural ground. (See paragraph 32b.)

90. PLACEMENT OF GRANULAR OR GRAVEL FILL. When a granular or gravel fill is being placed on frozen silt or frost-heaving material, the fill should be placed immediately after stripping or without stripping to avoid thawing the subgrade. A thawed subgrade becomes quagmire in which tractors bog down greatly delaying the work. To prevent delays in backfilling and consequent thawing, it is essential to have the fill material stockpiled adjacent to the work, since haul roads often break down under the heavy traffic.

Light buildings

91. TEMPORARY. When light temporary buildings are to be constructed where the active zone is 2 to 5 ft thick and composed of frost-heaving soils, a non-frost-heaving soil backfill should be placed to a sufficient height to provide drainage. Temporary buildings may be erected on sills placed directly on a well-drained fill without the use of an additional air space, since the fill will reduce and equalize the settlement as well as provide improved drainage, and since the air space between the floor beams is generally sufficient to dissipate the heat passing through the floor.

92. PERMANENT. For permanent type structures, an air space beneath the building is desirable to provide stability. (See paragraphs 63 and 64.)

Heavy buildings

93. AIR SPACES. The depth of heat transfer and thawing of frost in the ground below a heated building appears to be a function of the dimensions of the building. A space for air circulation under a structure will prevent the thawing of the permafrost beneath it and, with proper construction, will insure stability of the structure. (See paragraph 59.)

94. PILING OR PIERS. Stable structures can be built on frost-heaving material in arctic and subarctic regions if the structure is supported on piling embedded in permafrost with an air space between the floor and the ground for dissipation of heat from the buildings. Piers are seldom used for buildings because of the difficulties involved in suitably installing them. A tentative vertical dimension of the air space is one to two feet; under structures covering a large ground area, an air space of 2 ft or more is recommended. Where an air circulation space is used, the depth of the active zone will remain about as under natural conditions. Depth of embedment of piling in permafrost should be equal to at least twice the depth of the frost zone. When the temperature of the permafrost is just slightly below 0° C, the piles should be placed to depths greater than twice

the depth of the active zone. (See paragraph 62 of Main Report and paragraph 13 of Appendix I.)

95. SOLAR RADIATION. Under large, heated buildings such as airfield hangars, the permafrost table will be lower on the south side of the building area than on the north side because of the greater amount of solar radiation received on the south side. (See Plate I-17, Appendix I.) This may result in differential settlement of the structure and must be considered in the design.

96. CONCRETE FLOORS PLACED DIRECTLY ON THE GROUND. Concrete floors placed directly on the ground will permit greater heat transfer into the ground than other common types of floors. (See paragraph 59.)

97. EFFECT OF COARSE-GRAINED FILLS. A fill of coarse-grained material under the floor of a building is not effective as an insulator in preventing heat transfer into the ground. However, the fill will reduce and equalize the effect of settlement in the subgrade as well as provide improved drainage. Results of calculations based on data from field and laboratory tests made in connection with this investigation (Plate 23) indicate that depth of thaw is greater in coarse-grained material (sand and gravel) than in fine-grained material (silt or peat). That portion of a fill placed below the groundwater table will be somewhat more effective than the portion above the groundwater table in reducing the depth of thaw. However, because of the great depth of fill required (see Plate 23) in permafrost regions, no practical benefits can be obtained.

98. VERTICAL DISPLACEMENT OF BUILDINGS. Vertical displacement of buildings can be expected where they are supported on the natural ground surface. (See paragraph 61.)

99. DECENTRALIZATION OF SERVICE STRUCTURES. In permafrost areas, special service structures such as heating plants and powerhouses should be independent units located at a distance from hangars and other large structures to eliminate the fire hazard and to prevent the heat from the service structure from thawing out the permafrost under the hangar or other operational structures.

Utilities

100. UTILIDORS. Utilidors as well as other heat conductors placed underground cause thawing in the surrounding ground. In areas of frost-heaving soils over permafrost, utilidors should be built above ground with an air space between the bottom of the utilidor and the ground surface. They should be supported on posts extended well into permafrost.

Analyses of heat transfer in ground

101. DEPTH OF THAW. Depth of thaw in frozen ground can be approximated by the methods described in this report. (See paragraph 32c.) The depth of thaw in any soil is a function of (see paragraph 32b):

a. Degree-days above freezing, the thawing index, for the ground surface. This is determined by applying the proper correction factor for the particular surface to the thawing index based on air temperature for the locality being considered.

b. Thermal conductivity of the soil or other substances through which the heat must flow. This factor depends on the moisture content primarily and on the density, temperature, mineral composition, gradation, and particle shape of the material.

c. Thickness of each layer of material through which heat must flow. Most accurate calculations can be made when complete information is available concerning the physical characteristics of each layer.

d. The latent heat capacity, or the latent heat per cubic foot of material is equal to 143.4 times the number of pounds of water per cubic foot of material.

e. Heat necessary to warm material to melting point. This is a function of the volumetric heat capacity frozen and the differential between the mean annual temperature and the melting point. Under arctic conditions or where there is an appreciable differential between the mean annual surface temperature and the freezing point, the calculated depth of thaw by the method described herein would be somewhat greater than actual because the heat required to warm the ground below the thawing line to the melting point has been neglected.

f. Heat necessary to warm material above the melting point. This is a function of the volumetric heat capacity of the thawed material and the differential between the melting point and the average temperature of the thawed soil. This factor is not important when the depth of thaw is relatively small. The calculated depth of thaw, ignoring this factor, is also greater than actual.

g. Fluctuation in groundwater levels. This factor is not considered in the method described for determining depth of thaw except as an average soil moisture condition is assumed.

h. Heat transported by flowing surface or groundwater. This factor always increases the depth of thaw, and consideration should be given toward controlling it.

i. Convection of heat by water in coarse material. As water has its greatest density at 4° C, this high density water will tend to flow downward to the thawing surface where it loses heat, increases the depth of thaw, loses density, and rises to a higher elevation. This effect is dependent on the porosity of the material.

j. Natural surface vegetation.

(1) Natural surface vegetation acts as an insulator during the summer when it is dry and as a good thermal conductor during the winter when it is saturated and frozen.

(2) Natural surface vegetation disperses much heat during the summertime through transpiration.

(3) Removal of surface vegetation causes subsequent seasonal thawing to greater depths.

Methods of preventing heat transfer into the ground

102. METHODS OF PREVENTING HEAT TRANSFER INTO THE GROUND.

a. Materials which have low conductivity when dry are very poor insulators when wet. Very few insulating materials do not absorb water when it is available.

b. Insulating materials only retard the rate of heat transfer through them and do not prevent such heat transfer entirely. Thus, in time, a building floor which is well insulated at the ground surface to prevent heat transfer downward will be susceptible to settlement damage due to melting of permafrost. (See paragraph 59.)

c. The most effective method of preventing heat transfer into the ground under a building is by dissipating the heat into a moving air stream under the structure. Although air will move vertically when heated or cooled, it is generally impractical to allow much space for natural vertical movement under a building, therefore, artificial movement of air is the most certain method for wide buildings. (See paragraph 59.)

d. The effect of insulation in a runway base course is to retard the flow of heat into the ground in summer and out of the ground in winter; thus the effect on the mean annual temperature is very nearly the same as under natural conditions. (See paragraph 53.)

Conditions necessary for the preservation of permafrost

103. CONDITIONS NECESSARY FOR THE PRESERVATION OF PERMAFROST.

a. Artificial conditions are generally not as favorable for the preservation of permafrost as natural conditions.

b. The maximum rate of thaw upward at the bottom of permafrost is slow even when natural surface conditions have been changed most unfavorably. (See paragraph 43.)

c. The level of the permafrost surface may be raised by decreasing the degree-days of thaw and increasing the degree-days of freeze or by saturating coarse-grained fill material placed over it.

Stability of pavements

104. THEORY AND FINDINGS. The theory of the most generally accepted method of insuring no loss in strength of the subgrade due to frost action in temperate zones is to provide a thickness of pavement and base, not susceptible to frost action, which will prevent freezing of the subgrade. Where damage is caused by frost action soils encountered in the base or subgrade, these soils are commonly replaced by non-frost-action soils such as sands and gravels. However, depths of freeze or thaw are proportional to the degree-days of freezing or thawing, respectively. It has been shown in this report (Plate 23) that in subarctic regions with a thawing index of 3000 degree-days (Fairbanks, Alaska), dense

sand-gravel mixtures which are commonly used for fills cause deep thawing while low density materials such as peat and silt soils which are frost heaving and have low structural strength cause shallow thawing. It is obvious from the data presented that it would be impracticable in subarctic regions to replace frost-susceptible soils with a sufficient thickness of sand or gravel to prevent penetration of thaw into the subgrade. However, the field investigations in Alaska have shown that the non-frost-susceptible fills tend to absorb the differential heaving in underlying frost-susceptible subgrades. At the present time, the only design information available based on a reduction in strength of the subgrade due to frost action is that contained in Chapter 4, Part XII of the Engineering Manual for War Department Construction. Figure 4 of Chapter 4 shows the required combined thickness of flexible pavement and base for various wheel loads with three types of frost-susceptible subgrade soils. It is considered that this information, together with the results of California Bearing Ratio tests, provide the best information presently available for the design of base courses for flexible pavements and that it is adaptable for use in subarctic zones. Criteria for the design of base courses for rigid pavements, which are also considered adaptable for use in the Subarctic, are contained in Figure 5 of Chapter 4.

Summary

105. GENERAL. In general any form of construction which involves the removal of natural vegetation or the placing of a fill or floor of a building directly on the ground will tend to destroy permafrost. Construction which provides for the dissipation of heat laterally rather than into the ground or which shades the ground from the sun's rays will tend to preserve permafrost.

XI Recommendations for Future Investigations

106. NORTHWAY AIRFIELD. Continue periodic monthly ground temperature observations under the unheated hangar and adjacent runway installations until they appear stabilized. Make complete reconnaissance survey of the runway and hangar and submit recommendations for supplementary investigations necessary to complete the investigation at this site.

107. FAIRBANKS RESEARCH AREA, FAIRBANKS, ALASKA. The results of most ground temperature tests at the Fairbanks Research Area have been essentially the same during the past two years. These tests should be continued until 30 October 1950 with a reduced frequency of observation and discontinued at that time if the past trend continues. Those tests which show a progressive change from year to year should be continued.

108. INSTALLATIONS AT WEATHER STATIONS. Continue observations of ground temperatures at the various weather stations in Alaska. Obtain additional soil samples at these locations for determination of soils characteristics. Correlate ground and air temperatures with surface and soil characteristics. Service and recondition all ground temperature installations. Make additional installations at outlying Alaskan and Canadian stations.

109. TANGENTIAL ADFREEZING TESTS ON PILES. Make tests to determine the rate of refreezing of permafrost which has been thawed artificially when placing piles. These tests should be made in different sections of Alaska in different soil types.

110. PLATE LOADING AND ACCELERATED TRAFFIC TESTS. To check the base course design criteria contained in Chapter 4, Part XII of the Engineering Manual for War Department Construction, make plate loading and accelerated traffic tests in selected sections of Area No. 2 of the Fairbanks Research Area. Make similar investigations and tests in other sections of Alaska.

111. ADDITIONAL INSTALLATIONS AND STUDIES.

a. Observe ground and air temperatures in various sections of Alaska under existing buildings constructed with an air space under the floor.

b. At various points in Alaska, construct several typical bituminous- and gravel-surfaced runway test sections, 100 ft square, with several base course thicknesses, placed directly on natural ground surface. Observe ground and air temperatures, vertical movement and the results of test loading during the seasons of the year.

c. Make detailed observations and studies at different locations in Alaska to determine correction factors for depth of thaw calculations. This would include all types of subsoil including silt, sand, gravel, etc., all types of surface including moss, peat, gravel, blacktop, concrete, etc.

d. Make load and settlement tests on permanently frozen, coarse-grained, non-frost-heaving materials suitable for building foundations to determine the effect of thawing to depths of 30 to 50 ft.

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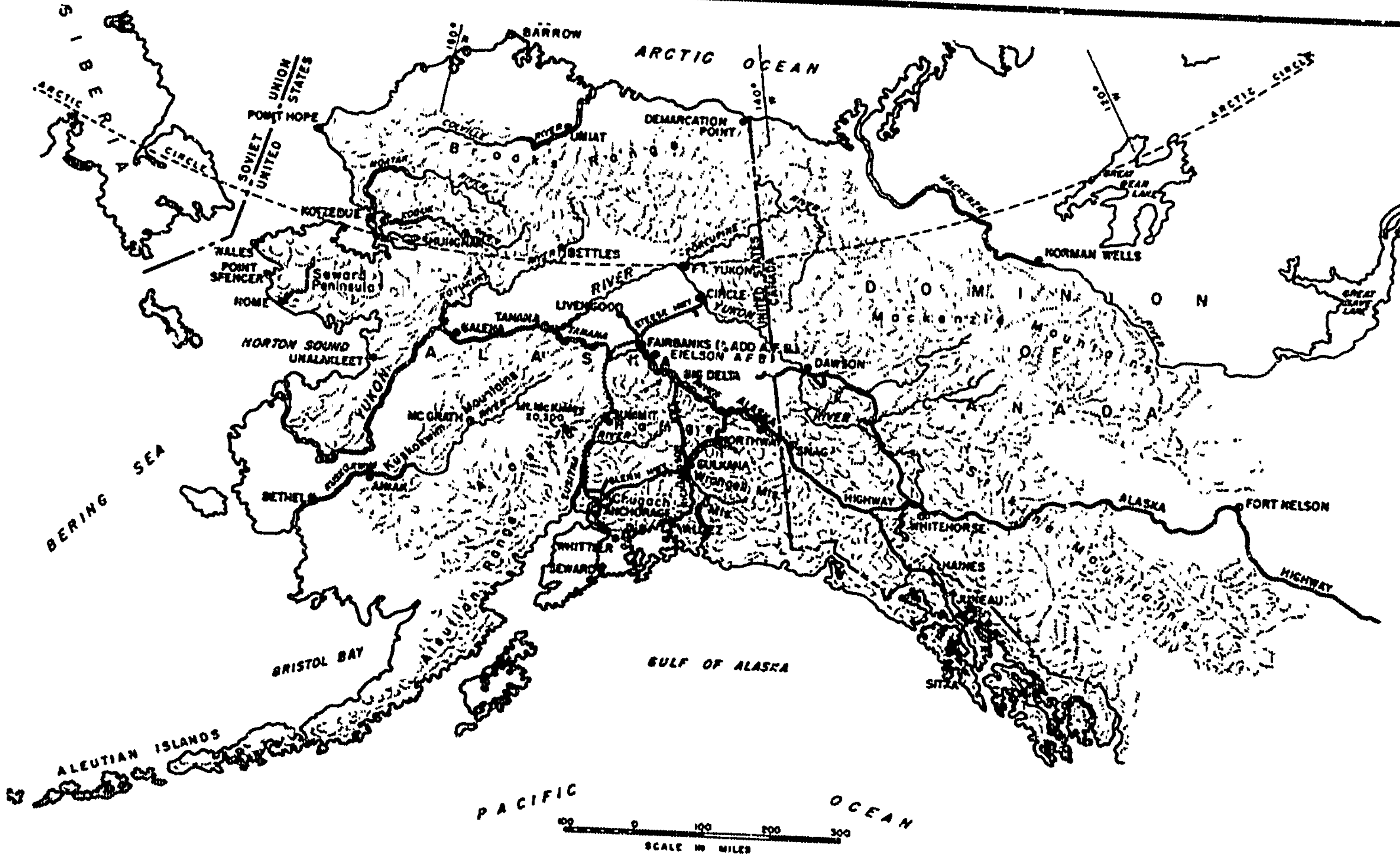


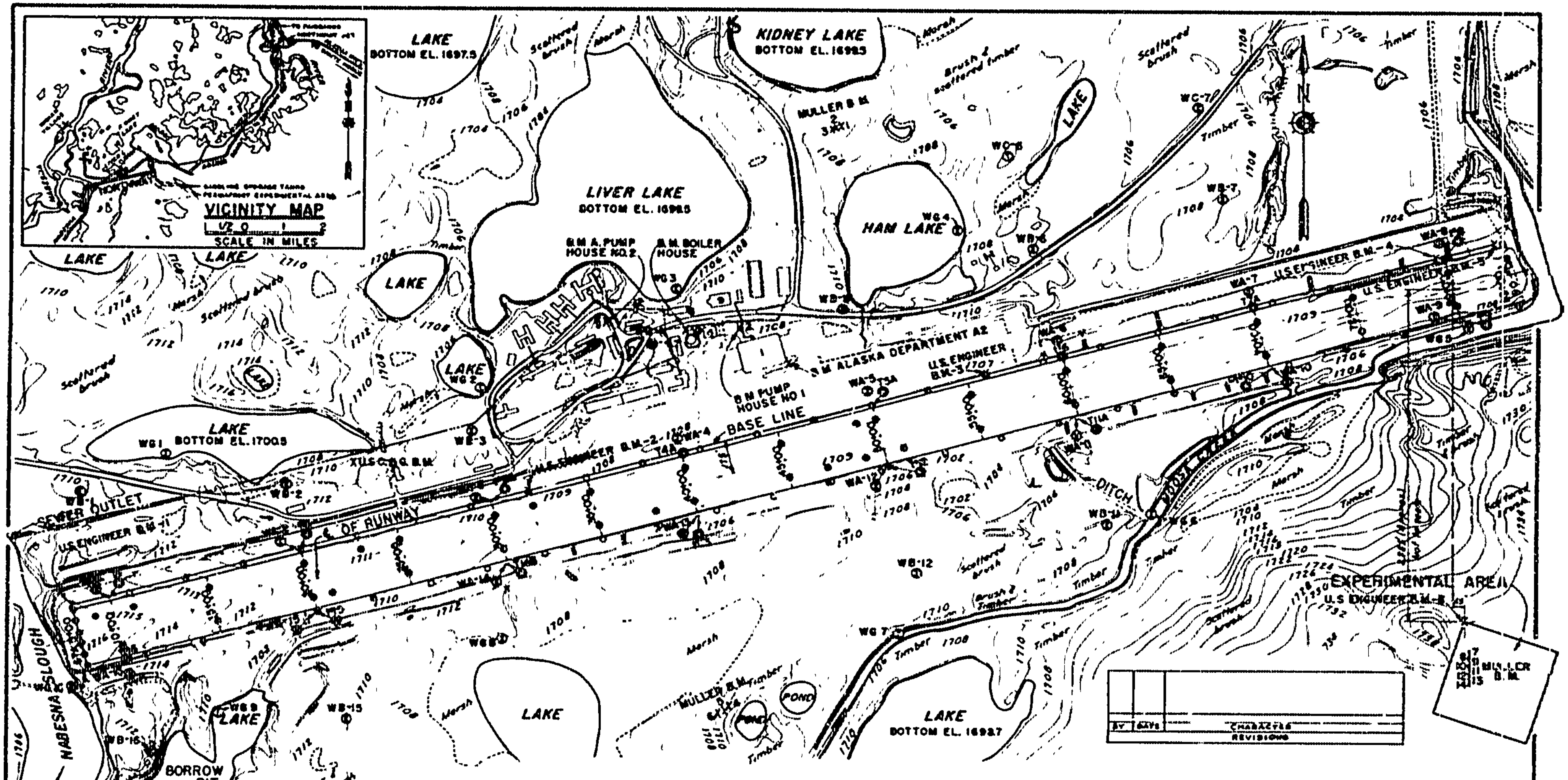
PERMAFROST INVESTIGATION

TERRITORY OF ALASKA

GENERAL OUTLINE MAP

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE I



BUILDING SCHEDULE

STRUCTURE OR BUILDING NO	SIZE	TYPE	PRESENT OFFICIAL USE
1	162.6' X 209.3'	FRAME	HANGAR
2	16' X 18'	FRAME	PUMP HOUSE & WELL NO. 1
3	16' X 18'	FRAME	PUMP HOUSE & WELL NO 2
4	55' X 65'	FRAME	POWER PLANT
6	20' X 32'	FRAME	BOILER HOUSE
7	40' X 104'	FRAME	FIRE STATION
8	32.4' X 100.3'	FRAME	GARAGE
9	64' X 104'	FRAME	ARMY MOTOR POOL
12	18' X 29'	LOG-HOUSE	N.C.O. CLUB

REFERENCES

FOR LOCATIONS OF OBSERVATION HOLES AND POINTS IN AND IN THE VICINITY OF BUILDINGS AND THE EXPERIMENTAL AREA SEE FOLLOWING PLATES IN APPENDIX I:

OBSERVATION POINTS IN EXPERIMENTAL AREA	PLATE I-25
OBSERVATION POINTS IN FIRE STATION	PLATE I-23
OBSERVATION POINTS IN BOILER HOUSE AND PUMP HOUSE	" I-24
OBSERVATION POINTS IN POWER HOUSE	" I-21
OBSERVATION POINTS IN MOTOR POOL BLDG	" I-20
OBSERVATION POINTS IN HANGAR	" I-16
OBSERVATION POINTS IN AND ADJACENT TO GARAGE	" I-22

LEGEND

- UTILIDOR LINE (WATER-STEAM-SEWER)
- X BENCH MARKS
- O RUNWAY LIGHTS
- STAFF GAGES
- FROST LEVEL OBSERVATION HOLES
- GROUND TEMPERATURE OBSERVATION HOLES
- T THERMOCOUPLE UNITS
- THERMOMETER STRINGS
- GROUND WATER OBSERVATION HOLES

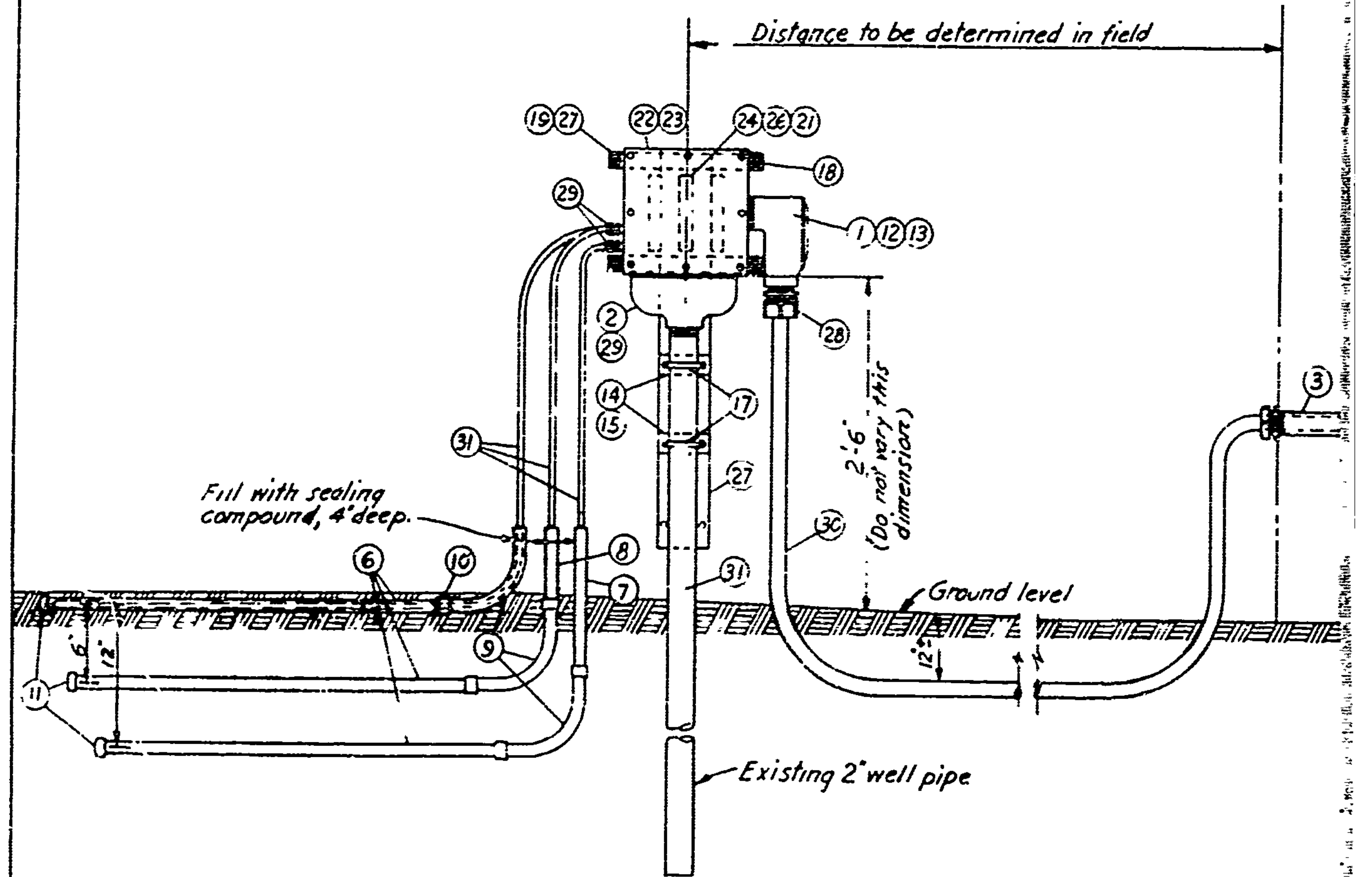
PERMAFROST INVESTIGATION
NORTHWAY AIRFIELD, ALASKA
RUNWAY & VICINITY
GENERAL PLAN

500' 250' 0 500'
SCALE IN FEET

IN 1 SHEET SHEET NO 1

U S ENGINEER OFFICE, ST PAUL, MINN. MAY 1950

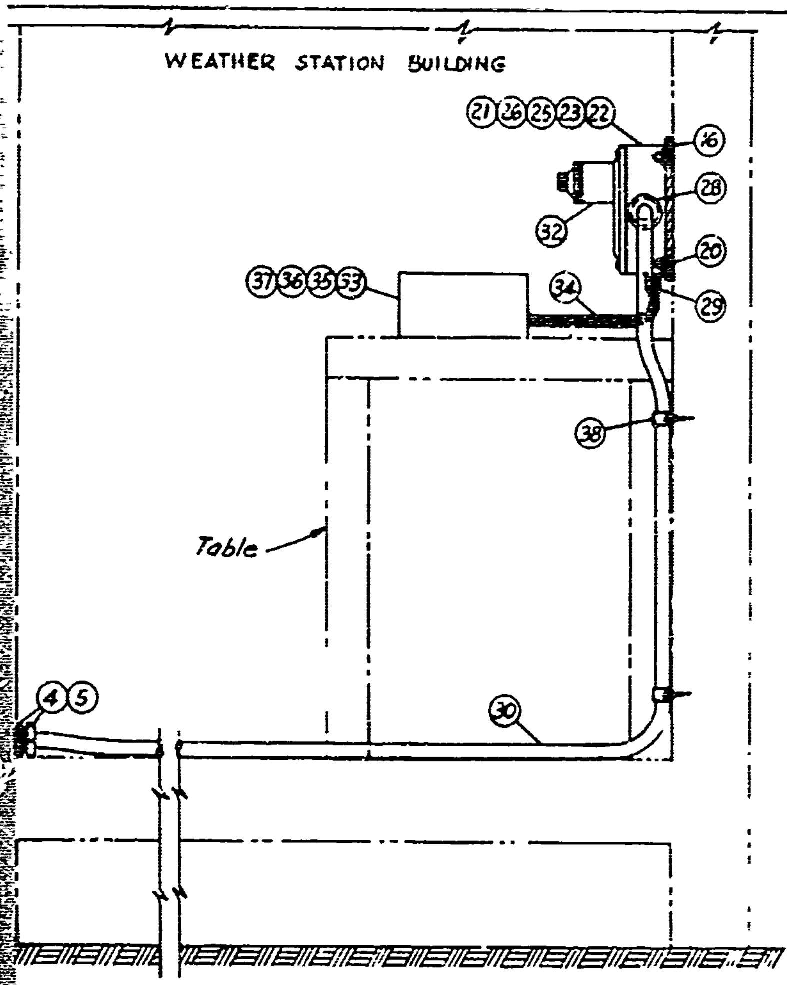
PLATE 2



LIST OF MATERIAL & WEIGHTS

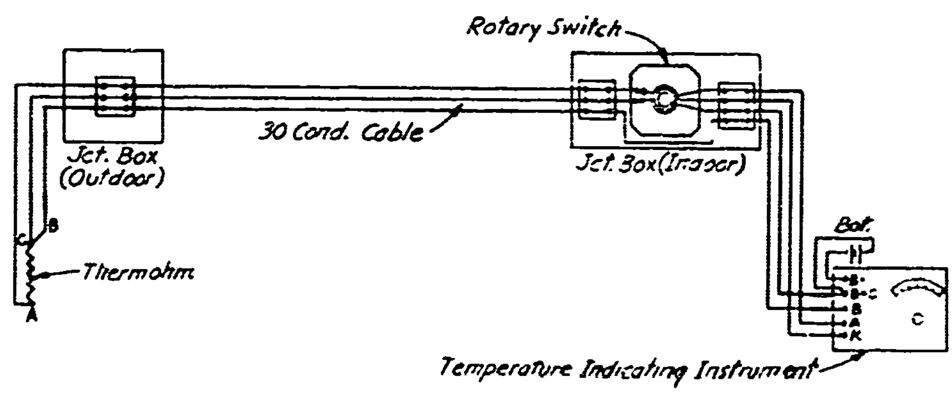
ITEM NO	QUAN.	DESCRIPTION		
1	1	Conduit fitting - 2". LB67, with cover & gask		
2	1	Conduit fitting - 2". A356 with gask (Appleton)		
3	1	Conduit - 1½" x 9" lg. Steel, galv.		
4	2	Conduit locknut - 1½" Steel, galv.		
5	2	Conduit bushing - 1½" Steel, galv.		
6	3	Conduit - ¾" x 3'-0" lg. Steel, galv.		
7	1	Conduit - ¾" x 12" lg. Steel, galv		
8	1	Conduit - ¾" x 6" lg. Steel, galv.		
9	3	Conduit elbow - ¾" - 90° - 4½" rad. Steel, galv		
10	5	Conduit coupling - ¾". Steel, galv		
11	3	Conduit cap - ¾". Steel, galv.		
12	1	Conduit close nipple - 2" x 2" lg. Steel, galv		
13	1	Conduit locknut - 2". Steel, galv.		
14	2	Block - 1¾" x 1½" x 4½" (Hard maple)		
15	2	Rubber gasket - ⅛" x 1½" x 4½"		
16	1	Plywood - ½" x 12" x 2'-0"		
17	2	U Bolt - ⅜" x 11" with hex. nut & lock washer.		
18	4	Bolt - ⅜" x 1½" with nut.		
19	4	Screw - ⁵⁄₁₆" x 1", ctsk. hd., with nut & lock washer.		
20	4	Screw - ⅜" x 1½", ctsk. hd., with nut.		

ITEM NO	QUAN.	DESCRIPTION
21	12	Screw - ³⁄₁₆" x ⅜", Rd. hd
22	2	Junction box - 10½" x 10½" x 3" (Russell & Stoll No. 21
23	12	Pipe plug - ⅜"
24	3	Terminal block - (10 Pole)
25	3	Terminal block - (9 Pole)
26	4	Rubber gasket - ⅛" x 1" x 7½"
27	1	Support frame (Aluminum channel & 2 - ⅜" x 1½" x 1'-2" b
28	2	Cable connector - 2" - CGB6915
29	10	Cable connector - ¾" - CGB3894
30		Ft. Cable - 30/C - No. 16
31	9	Thermohm & 3/C - No 16 cable
32	1	Rotary switch & leads
33	1	Temperature indicating instrument.
34	1	Set of 4 lead wires for instrument.
35	2	Dry cells & leads.
36	1	Rubber covered battery cable with amphenol plug & [illegible]
37	1	Check coil.
38	12	Pipe strap - 1½" Steel, galv.



STATIONS

U.S WEATHER BUREAU	C.A.A.
Barrow	Aniak
Kotzebue	Bettles
Mc.Grath	Big Delta
Point Hope	Fort Yukon
Summit	Galena
Wales	Gulkana
	Shungnak
	Tanana
	Unalakleet



TYPICAL WIRING DIAGRAM
SHOWING CIRCUIT FOR ONE THERMOHM

DIAL NO. ON SWITCH	1	2	3	4	5	6	7	8	9
DEPTH OF THERMOHMS	0.0	0.5	1.0	2.0	4.0	7.0	11.0	16.0	22.0

PERMAFROST INVESTIGATION
TYPICAL RESISTANCE THEMOMETER
INSTALLATION AT ALASKAN
WEATHER STATIONS

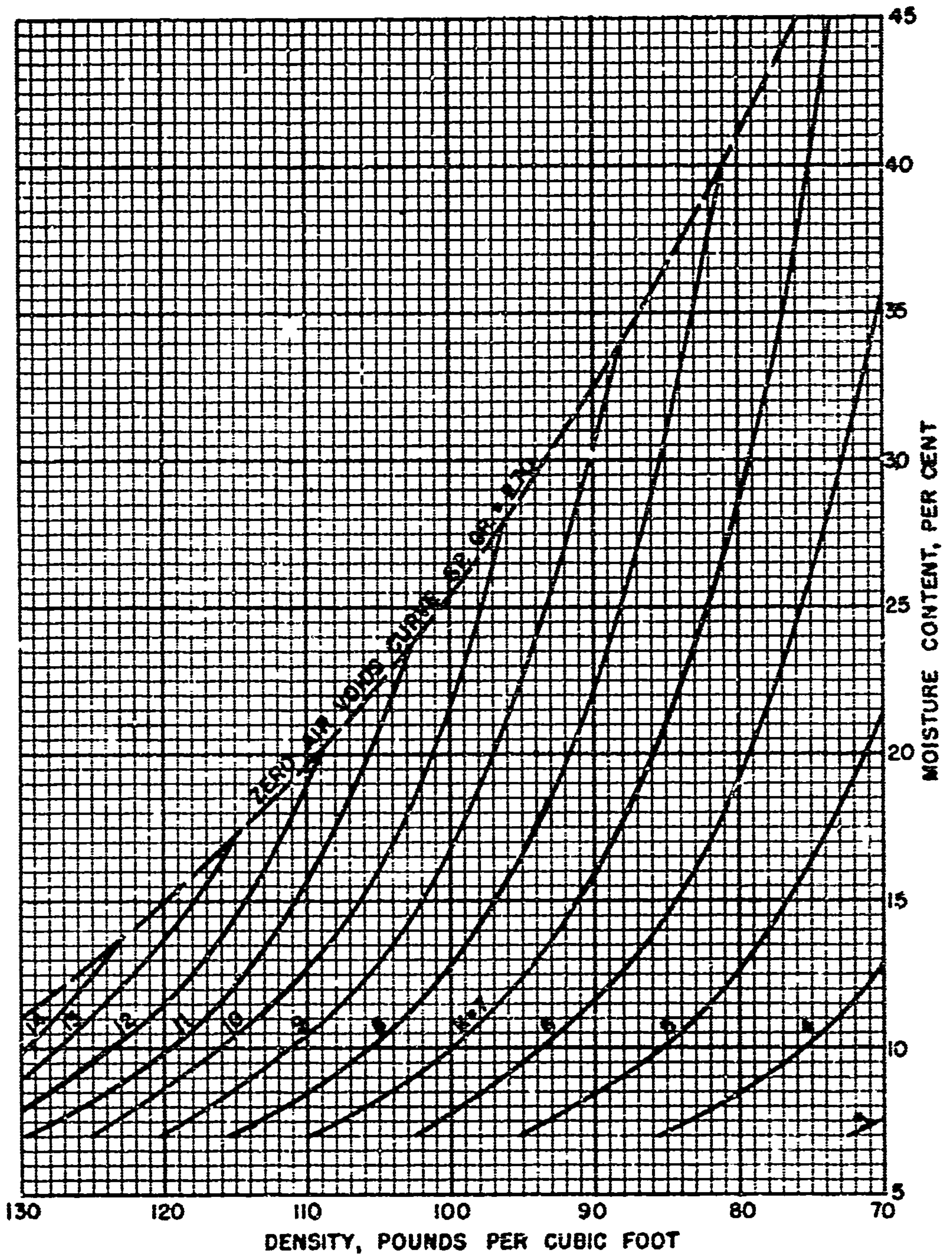
12" 9" 6" 3" 0 1'
SCALE

U.S. ENGINEER OFFICE, ST. PAUL, MINN. MAY 1950

SUBMITTED: APPROVED:

ENGINEER COL. CORPS OF ENGINEERS

PLATE 3



NOTE:
THERMAL CONDUCTIVITY "K" IS EXPRESSED IN BTU PER SQ. FT. PER UNIT THERMAL GRADIENT IN °F PER INCH. VALUES OF "K" SELECTED FROM THE GRAPH MUST BE DIVIDED BY 12 TO CONVERT TO BTU PER SQ. FT. PER UNIT THERMAL GRADIENT IN °F PER FOOT.

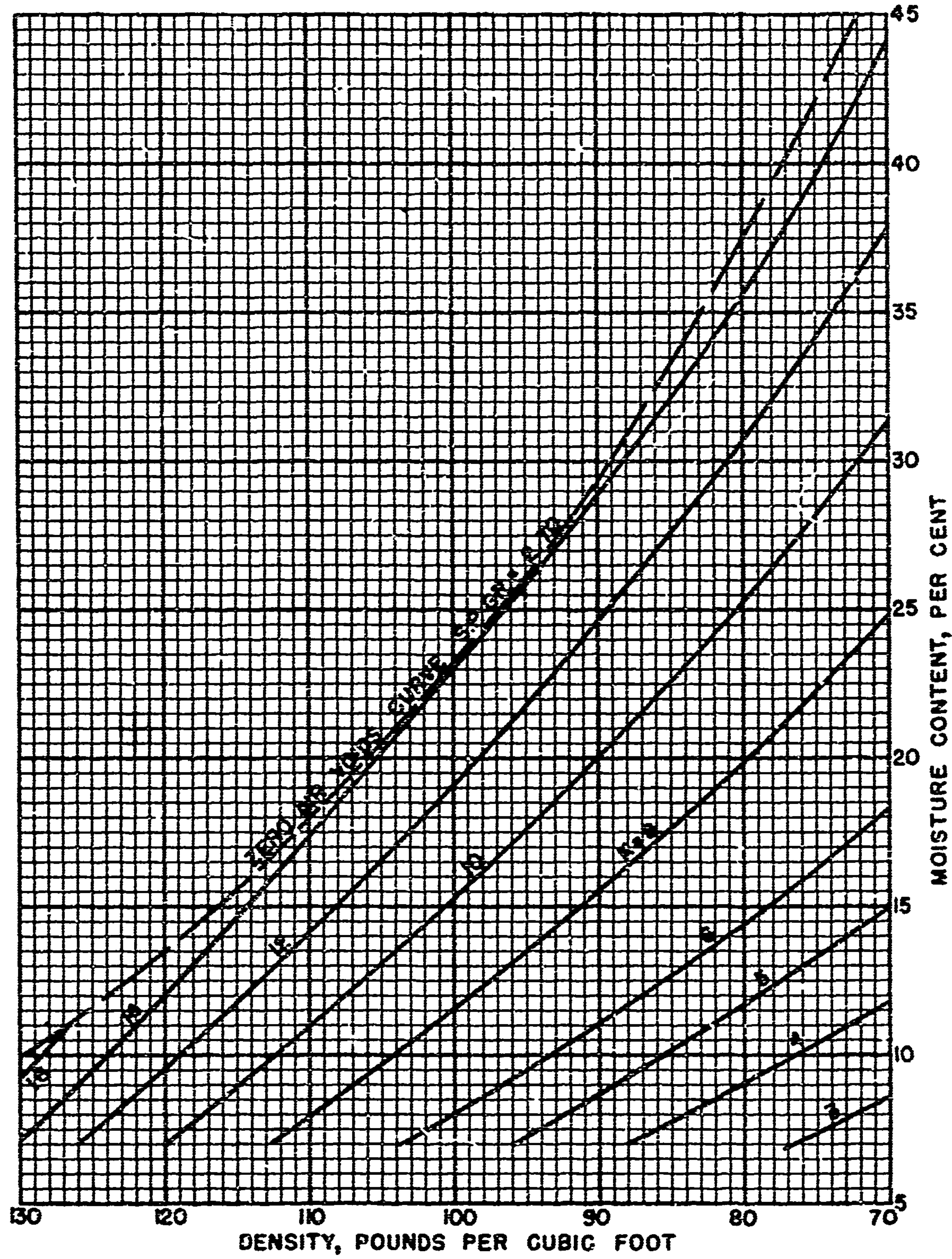
PERMAFROST INVESTIGATION

LABORATORY RESEARCH, UNIV. OF MINN.

AVERAGE THERMAL CONDUCTIVITY
FOR SILT AND CLAY SOILS
UNFROZEN, MEAN TEMPERATURE 40°F

CORPS OF ENGINEERS, ST PAUL, MINN. MAY 1950

PLATE 4



NOTE:
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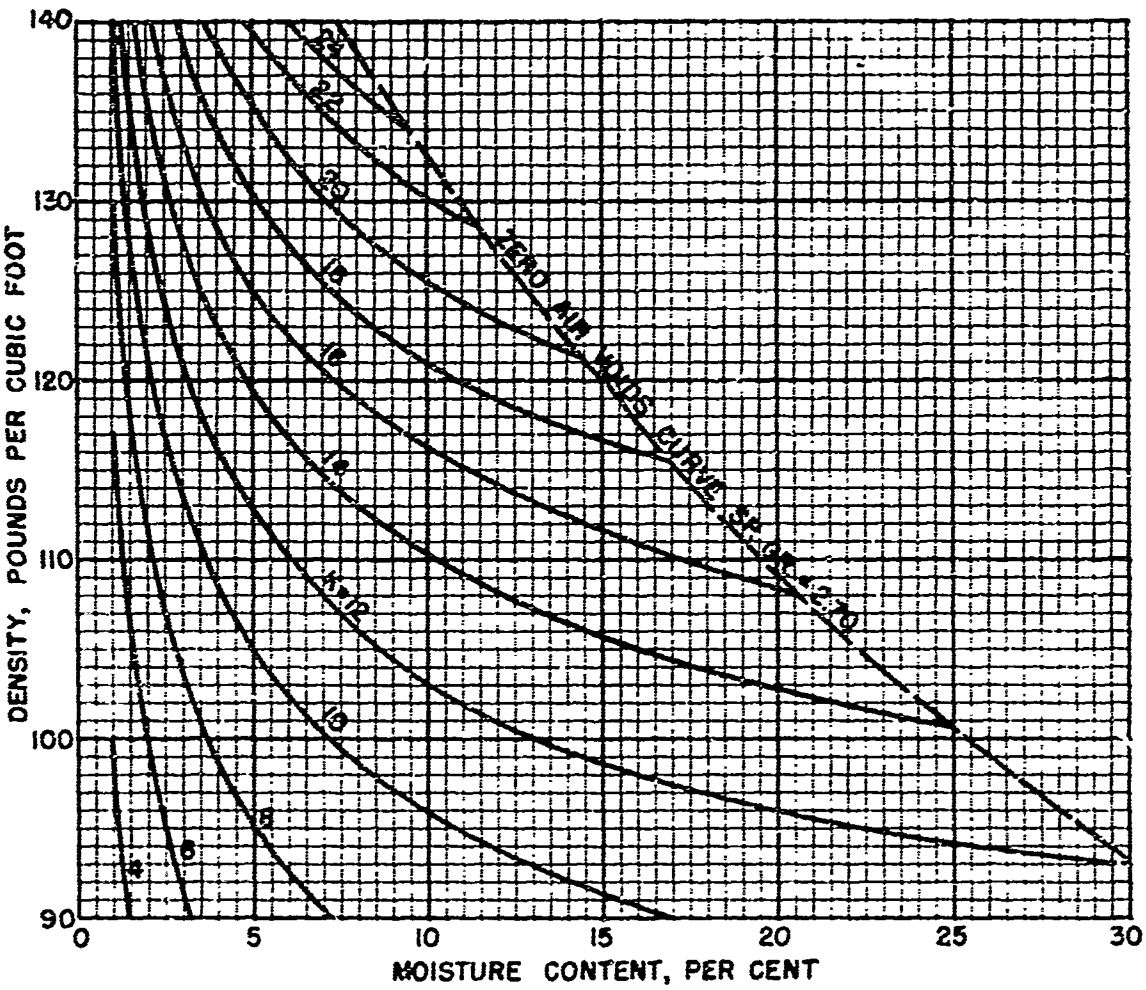
PERMAFROST INVESTIGATION
LABORATORY RESEARCH, UNIV. OF MINN.
AVERAGE THERMAL CONDUCTIVITY
FOR SILT AND CLAY SOILS
FROZEN, MEAN TEMPERATURE 25°F.

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY, 1950

PLATE 5



NOTE:
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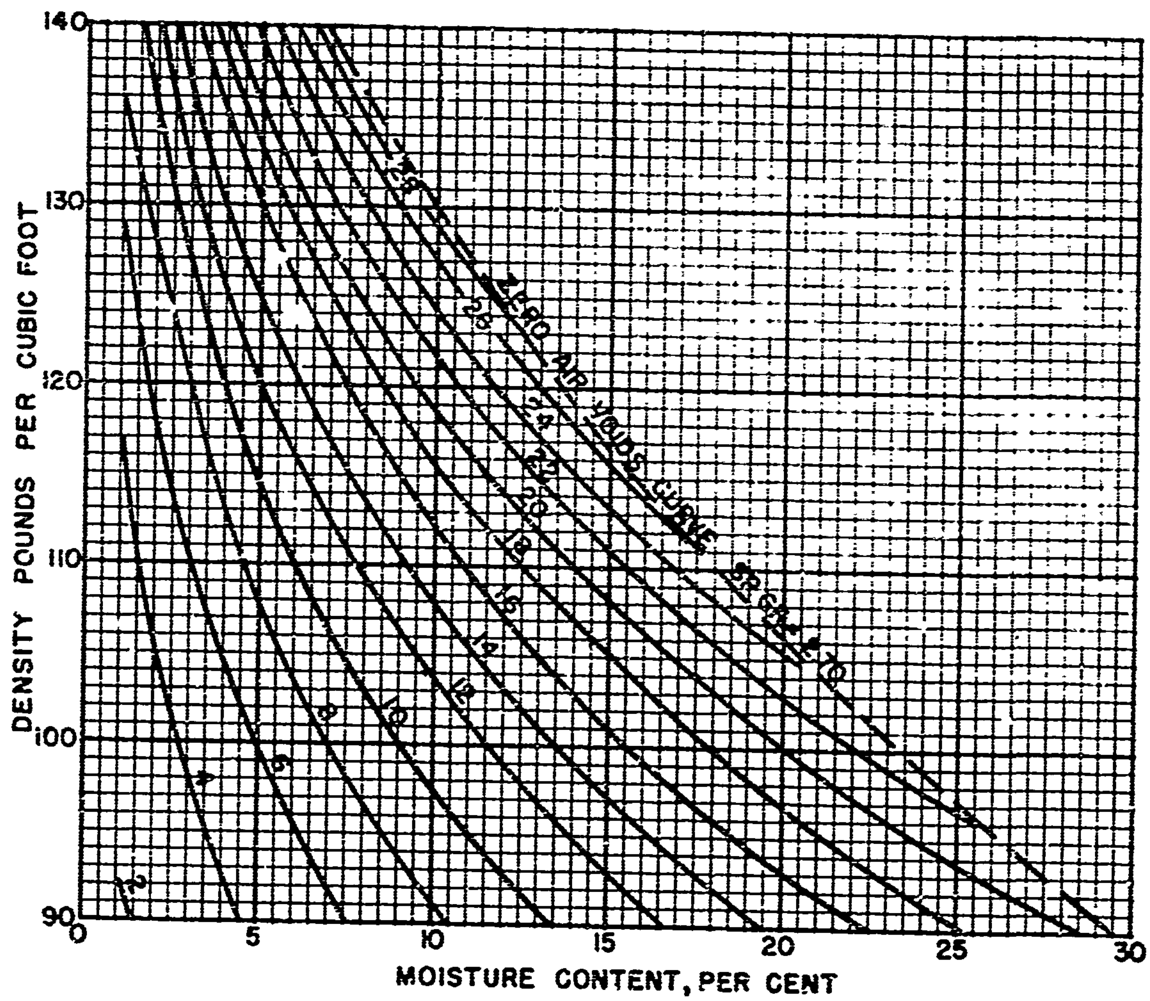
PERMAFROST INVESTIGATION
LABORATORY RESEARCH, UNIV. OF MINN.
AVERAGE THERMAL CONDUCTIVITY
FOR SANDY SOILS
UNFROZEN, MEAN TEMPERATURE 40°F
CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 6



NOTE:

THERMAL CONDUCTIVITY "K" IS EXPRESSED IN BTU PER SQ. FT. PER UNIT THERMAL GRADIENT IN °F PER INCH. VALUES OF "K" SELECTED FROM THE GRAPH MUST BE DIVIDED BY 12 TO CONVERT TO BTU PER SQ FT PER UNIT THERMAL GRADIENT IN °F. PER FOOT.

PERMAFROST INVESTIGATION

LABORATORY RESEARCH, UNIV. OF MINN.

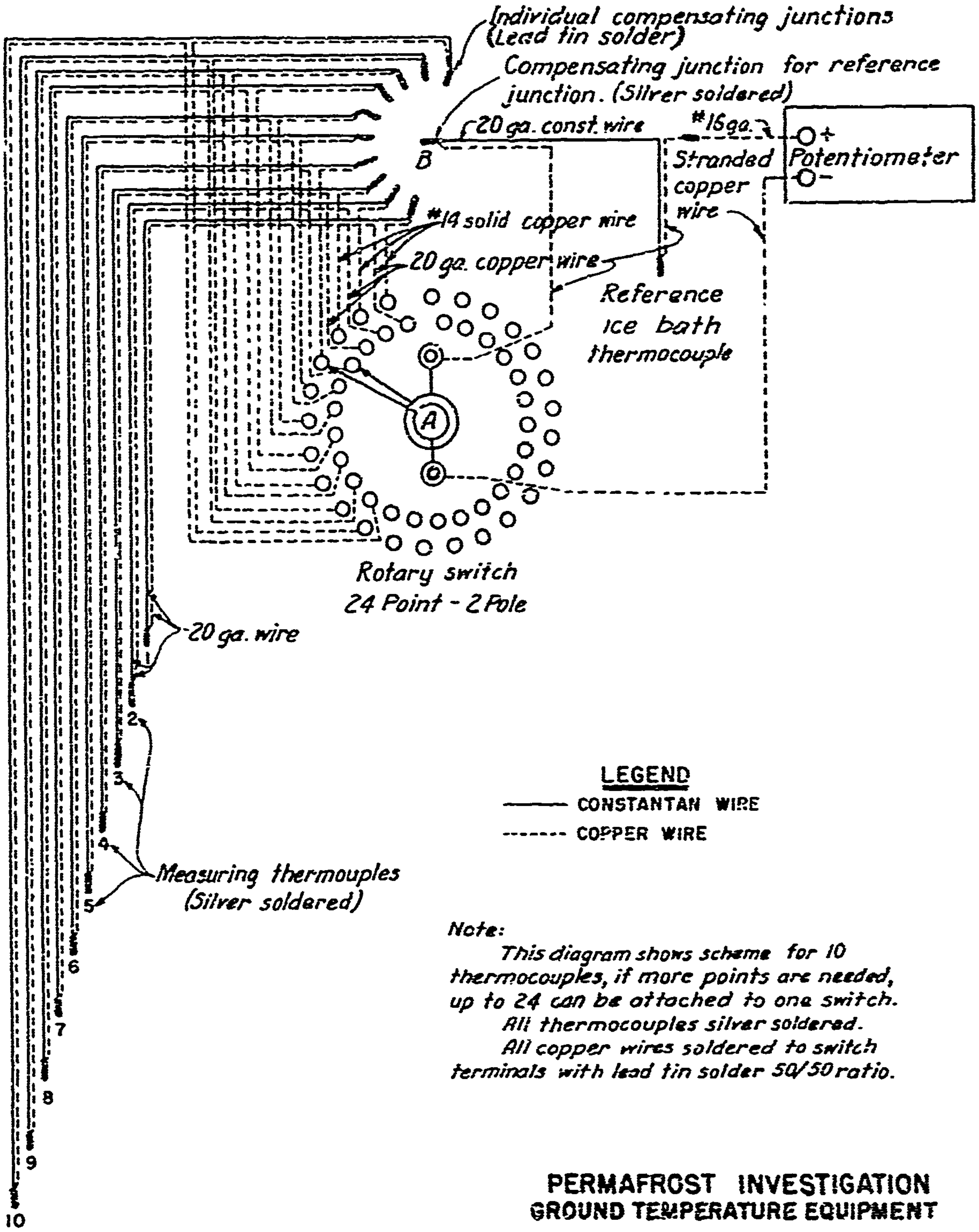
AVERAGE THERMAL CONDUCTIVITY

FOR SANDY SOILS

FROZEN, MEAN TEMPERATURE 25°F.

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 7



LEGEND

——— CONSTANTAN WIRE

------- COPPER WIRE

Note:

This diagram shows scheme for 10 thermocouples, if more points are needed, up to 24 can be attached to one switch.

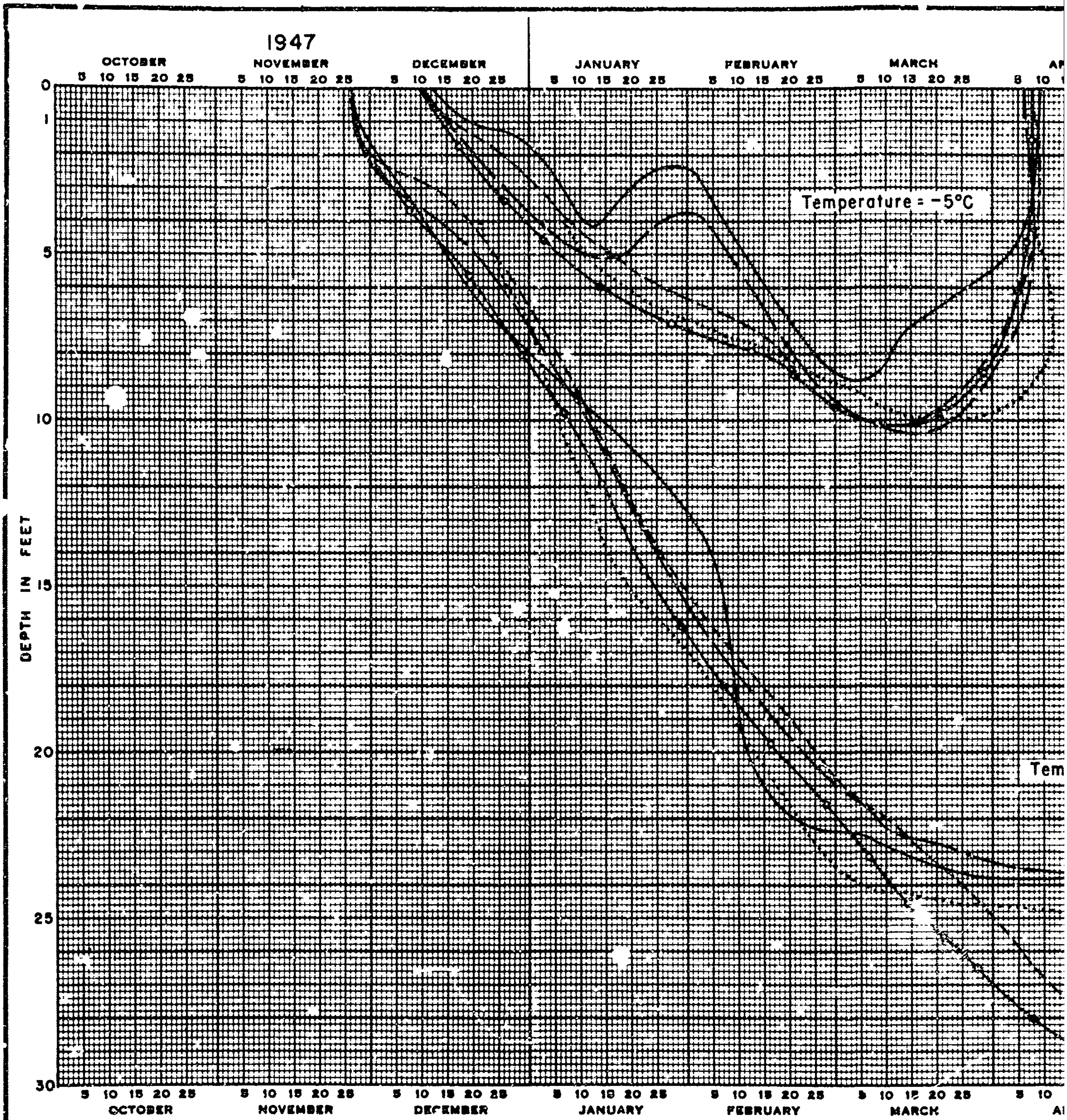
All thermocouples silver soldered.

All copper wires soldered to switch terminals with lead tin solder 50/50 ratio.

PERMAFROST INVESTIGATION
GROUND TEMPERATURE EQUIPMENT

THERMOCOUPLE DIAGRAM
MULTIPLE CONSTANTAN-
COPPER WIRE METHOD
GROUND TEMPERATURE EQUIPMENT

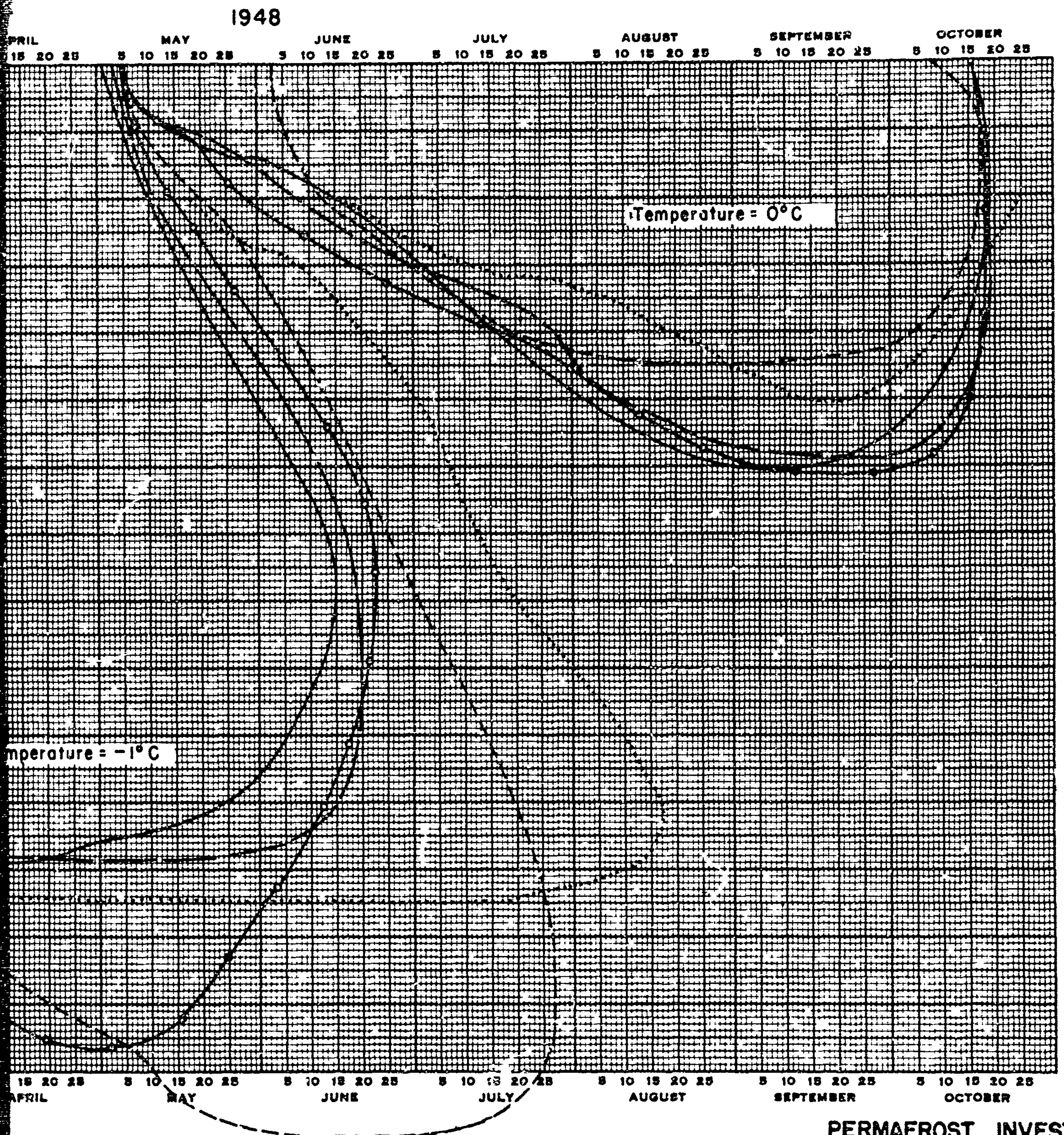
CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950



LEGEND

TTA 1 11 THERMOCOUPLES PLACED IN 3/4" PIPE NO INSULATION
TTA 2 11 THERMOCOUPLES PLACED IN 3/4" PIPE OIL INSULATION
TTA 3 11 THERMOCOUPLES IN GROUND NO INSULATION
TTA 4 4 NICKEL THERMOHMS IN GROUND NO INSULATION
TTA 8 11 THERMOCOUPLES IN 1½" PIPE SAND INSULATION

A



PERMAFROST INVESTIGATIO

FIELD RESEARCH FAIRBANKS, ALAS

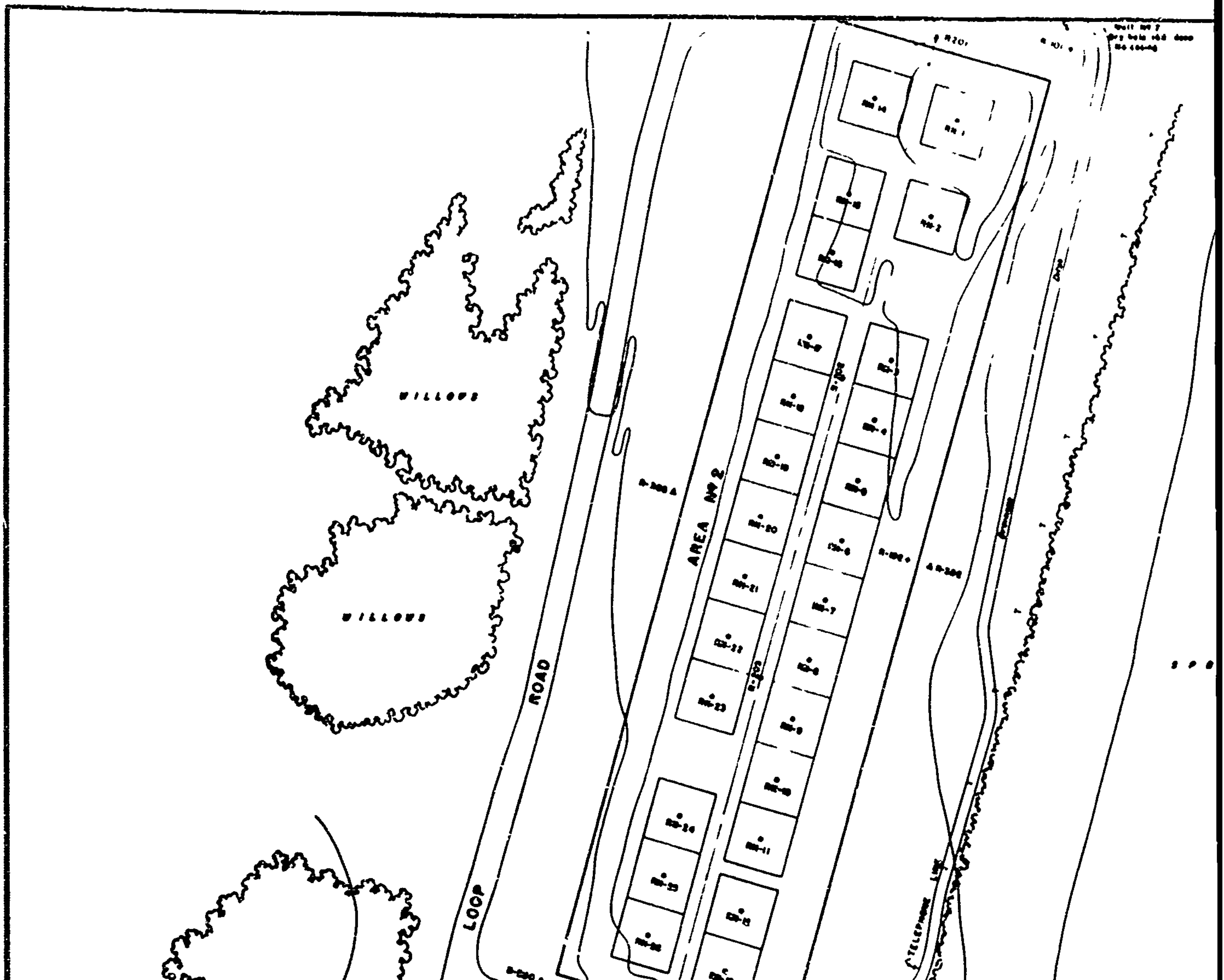
COMPARISON OF GROUND TEMPERAT

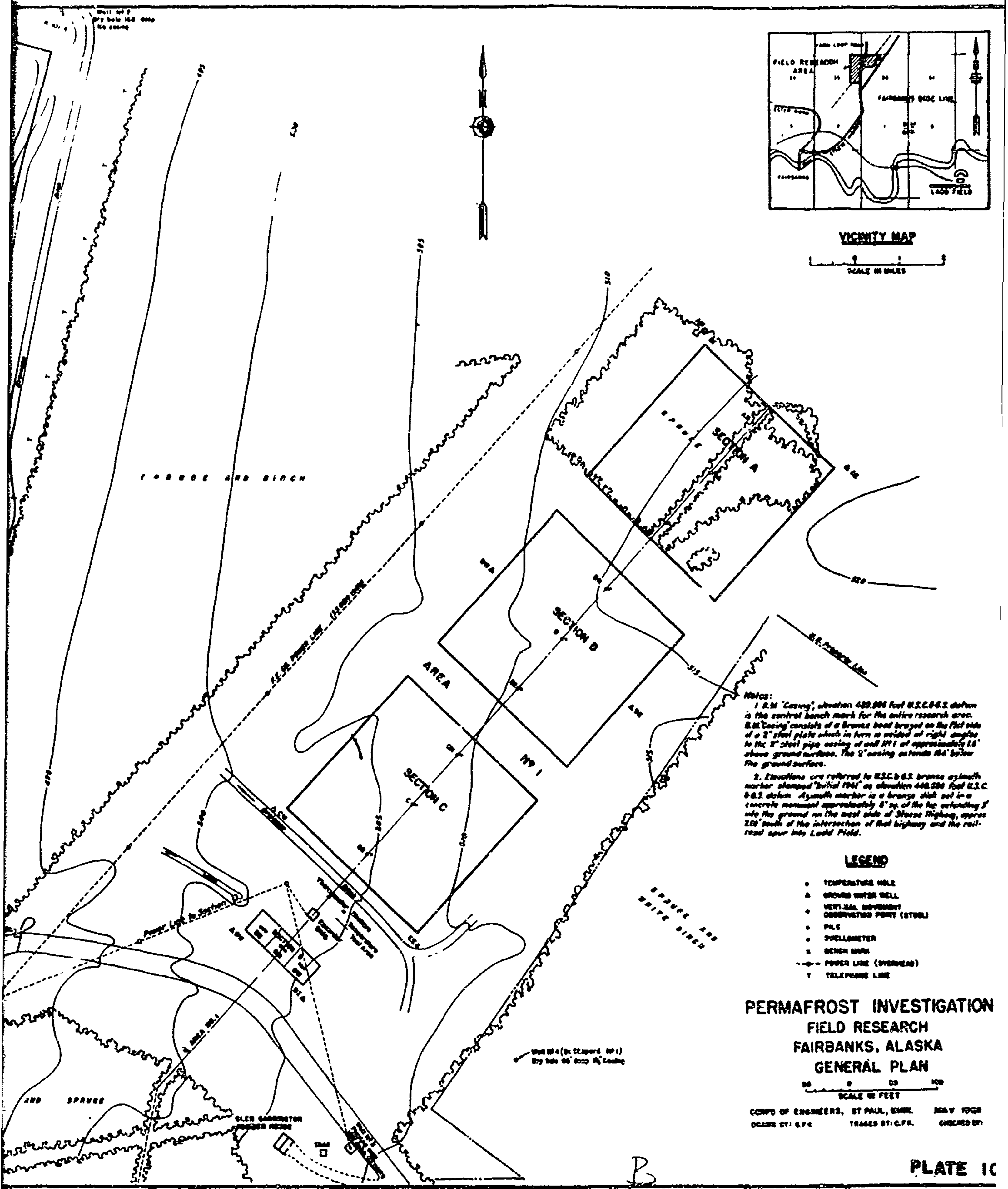
TESTING EQUIPMENT

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY

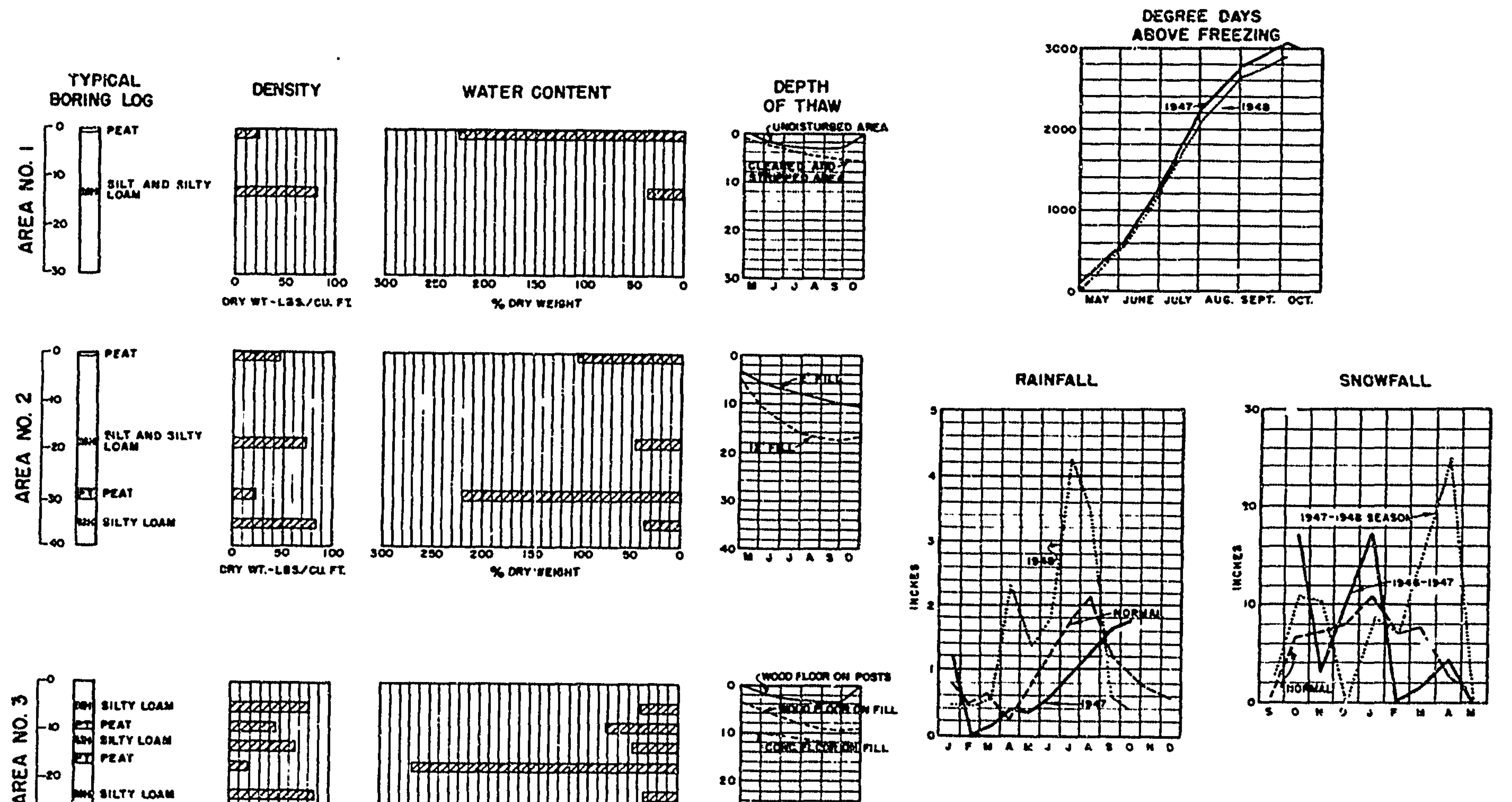
B

PL


WILLOWS
WILLOWS
AREA Nº 2
FARM
LOOP
ROAD
AREA
Nº 3
ACCESS
ROAD
BIRCH AND SPRUCE



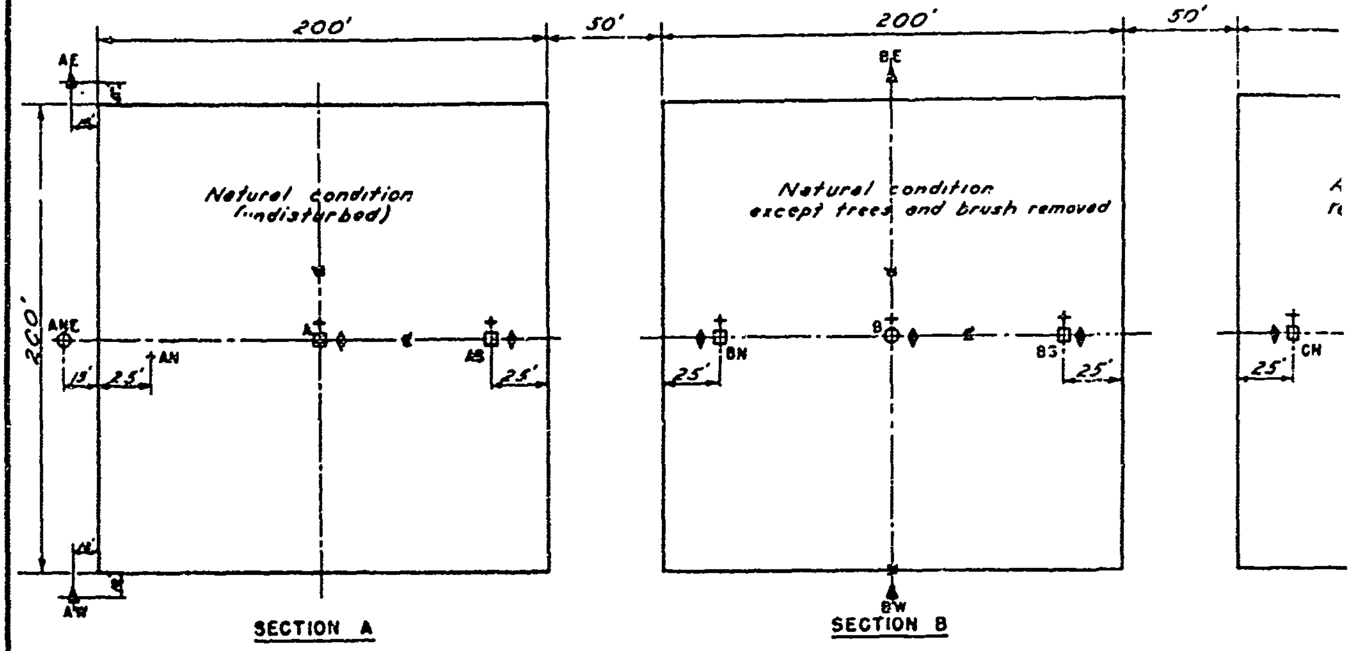
VICINITY MAP
SCALE IN MILES
FIELD RESEARCH AREA
FAIRBANKS
LADD FIELD
SPRUCE AND BIRCH
SECTION A
SECTION B
SECTION C
AREA
SPRUCE AND WHITE BIRCH
AND SPRUCE
Power Line to Section
Notes:
LEGEND
TEMPERATURE HOLE
GROUND WATER WELL
VERTICAL MOVEMENT OBSERVATION POINT (STEEL)
PILE
BENCH MARK
POWER LINE (OVERHEAD)
TELEPHONE LINE
PERMAFROST INVESTIGATION
FIELD RESEARCH
FAIRBANKS, ALASKA
GENERAL PLAN
SCALE IN FEET
CORPS OF ENGINEERS, ST PAUL, MINN.
PLATE 1



PERMAFROST INVESTIGATION
FIELD RESEARCH-FAIRBANKS, ALASKA
TYPICAL DATA

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

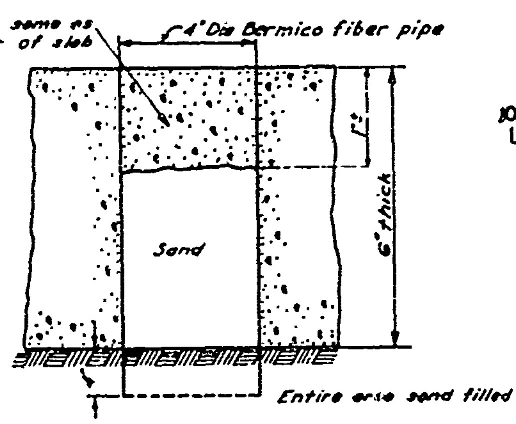
PLATE II



PLAN

100 50 0 100

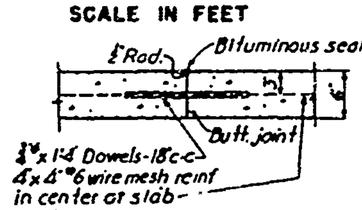
SCALE IN FEET



DETAIL OF SAMPLE SLEEVES

0" 3" 6" 9" 12"

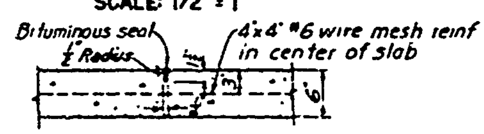
SCALE: 3" = 1'-0"



CONSTRUCTION JOINT

12" 6" 0 1' 2'

SCALE: 1/2" = 1'



TRANSVERSE DUMMY JOINT

12" 6" 0 1' 2'

SCALE: 1/2" = 1'

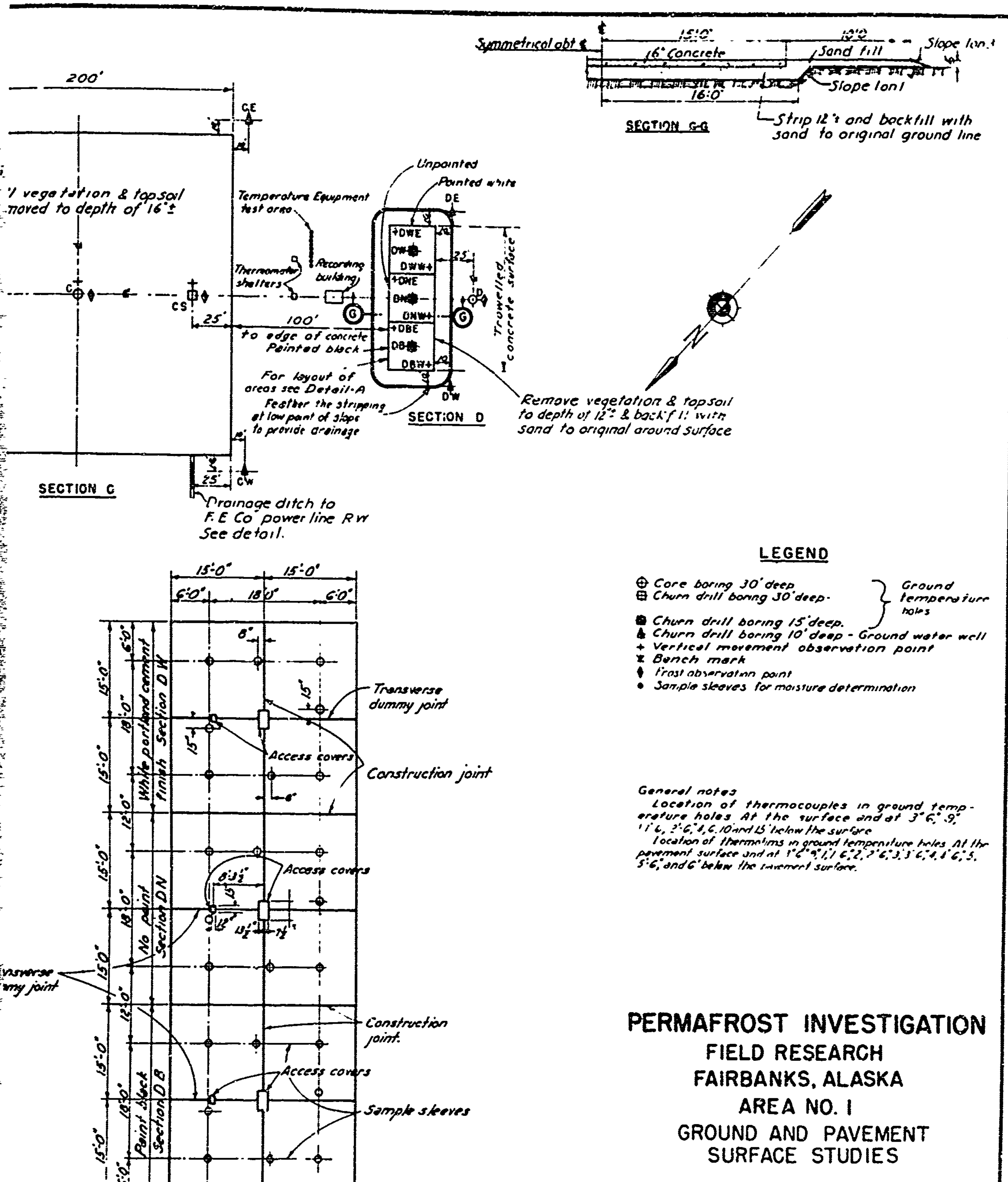
DETAIL OF DRAINAGE DITCH SECTION C

Drainage ditch as shown on section-C, location to be established in field.

Cut ditch 12 deep at origin in section C and maintain 0.5% grade to outfall at power line right of way

BY	DATE	CHARACTER

REVISIONS



LEGEND

- ⊕ Core boring 30' deep
- ⊞ Churn drill boring 30' deep
- ■ Churn drill boring 15' deep. } Ground temperature holes
- ▲ Churn drill boring 10' deep - Ground water well
- + Vertical movement observation point
- ⌛ Bench mark
- ♦ Frost observation point
- • Sample sleeves for moisture determination

General notes

Location of thermocouples in ground temperature holes At the surface and at 3", 6", 9", 1'6", 2'6", 4', 6', 10' and 15' below the surface

Location of thermohms in ground temperature holes At the pavement surface and at 1", 6", 9", 1', 1'6", 2', 2'6", 3', 3'6", 4', 4'6", 5, 5'6", and 6' below the pavement surface.

PERMAFROST INVESTIGATION
FIELD RESEARCH
FAIRBANKS, ALASKA
AREA NO. 1
GROUND AND PAVEMENT SURFACE STUDIES

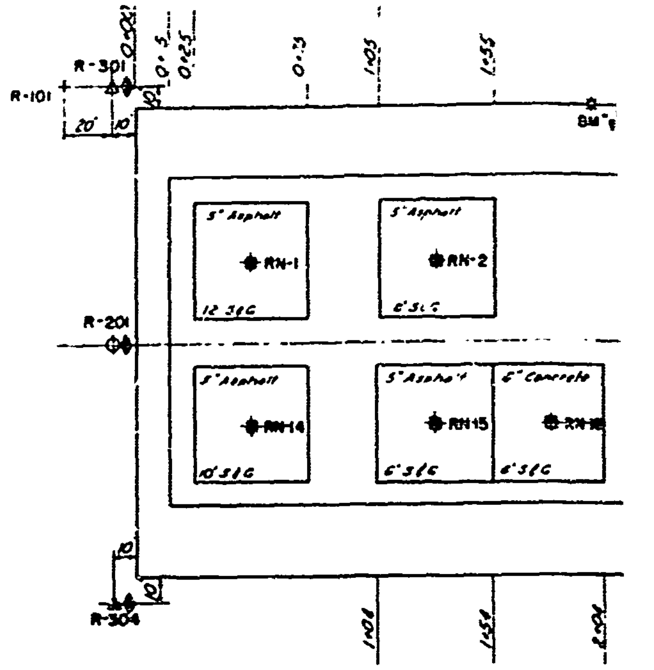
SCALE AS SHOWN

CORPS OF ENGINEERS ST PAUL, MINN MAY 1950

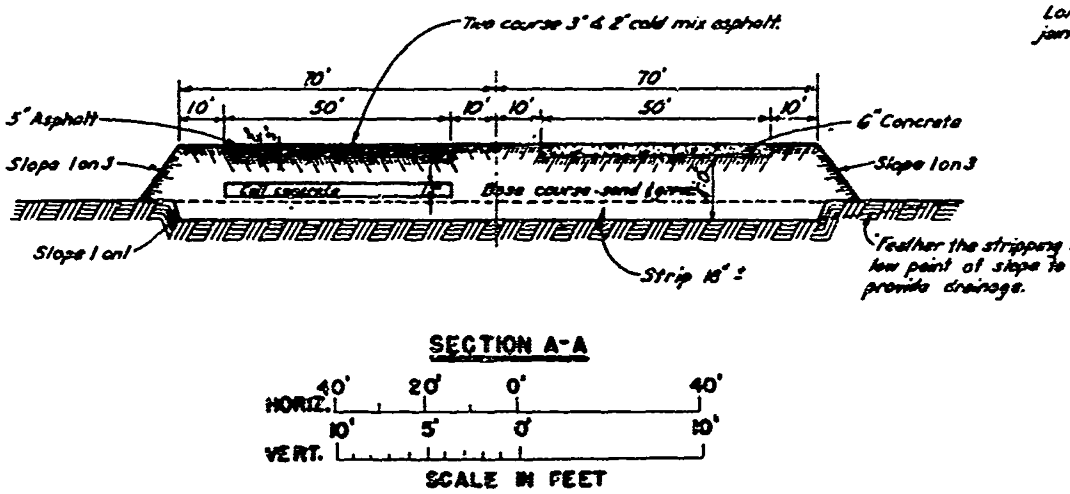
PLATE 12

New section temperature hole and design number	Original program boring hole log no.	Original program design number
RN-1	R-1	None (1)
RN 2	None	None (2)
RN 3	R-5	R-22
RN 4	R-6	None (3)
RN-5	R-7	R 13
RN 6	R-8	R-14
RN-7	R-9	R-15
RN-8	R-10	R-21
RN-9	R-11	R-6
RN-10 (6)	R-12 (5)	R-7
RN-11	R-13	R-23
RN-12	None	R-3
RN-13	None	R-18
RN-14	R-16	None (1)
RN-15	None	R-1
RN-16	None	R-16
RN-17	R-20	R-20
RN-18	R-21	None (4)
RN-19	R-22	R-26
RN-20	R-23	R-25
RN-21	R-24	R-11
RN-22	R-25	R-10
RN-23	R-26	R-9
RN-24	R-28	R-28
RN-25	R-29	R-29
RN-26	R-30	R-30

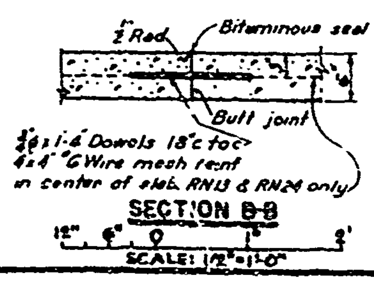
(1) New section in program requested by Office, Chief of Engineers.
(2) Not in original program. Original R-24 revised to avoid duplication in design.
(3) Not in original program. Original R-8 revised due to lack of sand.
(4) Not in original program. Original R-5 revised to provide thicker pavement.
(5) Original design R-12 was eliminated due to lack of foam compound for mixing cell concrete.
(6) Changed from medium to low density cell concrete due to lack of sand.



Longitudinal construction joint see section



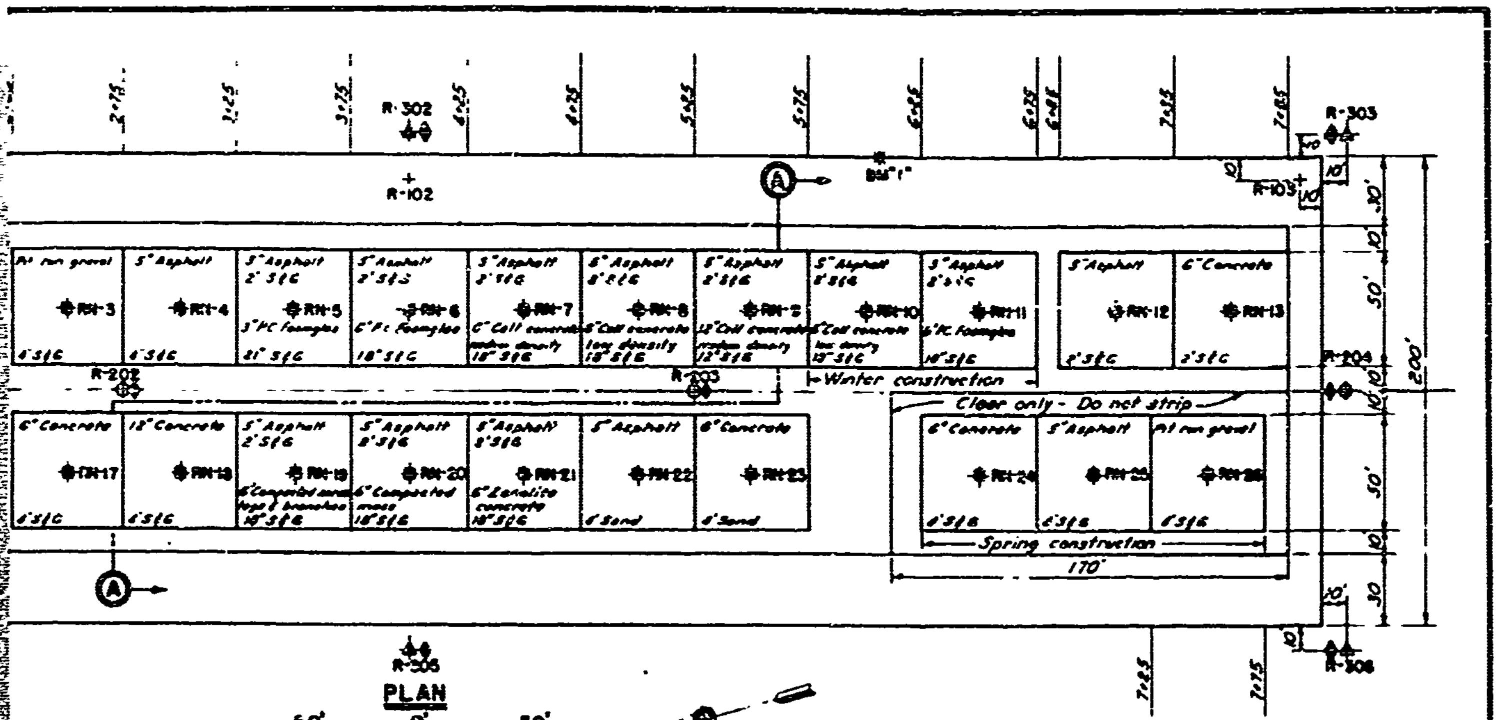
SECTION A-A



SECTION B-B

SCALE: 1½"=1'-0"

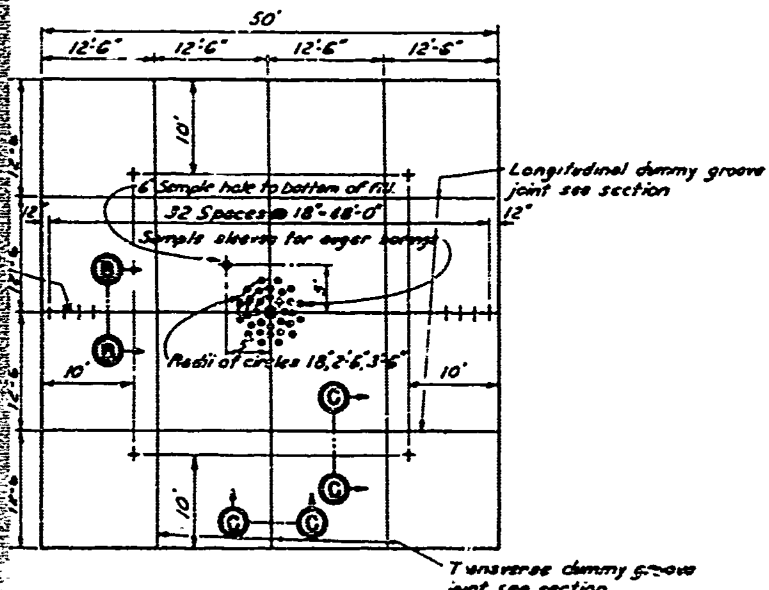
BY	DATE	CHARACTER
		REVISIONS



PLAN

50' 0' 50'

SCALE IN FEET



TYPICAL PAVING SECTION

20' 10' 0 20'

SCALE: 1" = 20'

LEGEND

- Vertical movement observation point.
- 30' Core boring (Ground temperatures observed to 30' depth below top of fill.)
- 10' Churn drill boring (Ground water well.)
- 15' Churn drill boring (Ground temperatures observed to 15' depth below top of fill, except to 25' depth for holes RN1 and RN14, and to 23' depth for hole RN2
- Bench mark
- Frost observation point.

Note:

Thermocouples in ground temperature holes RN-1, RN-2 and RN-14 are located at the pavement surface and at 6", 1', 1'-6", 2', 2'-6", 3', 3'-6", 4', 4'-6", 5', 6', 7', 8', 9', 10', 11', 12', 13', 14', 15', 16', 20' and 25' below the surface except that in RN-2 the lowest thermocouple is at 23' instead of 25'.

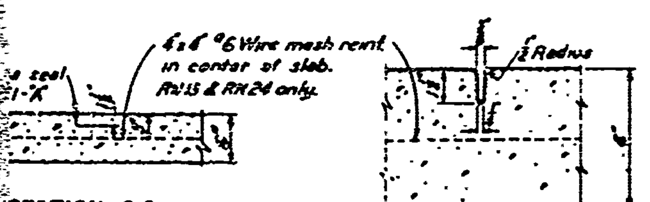
Thermocouples in ground temperature holes RN-3 and RN-26 are located at the gravel surface and at 6", 1', 1'-6", 2'-6", 4', 6', 10' and 15' below the surface.

Thermocouples in ground temperature hole RN-18 are located at the pavement surface and at 1', 1'-6", 2', 2'-6", 3'-6", 5', 7', 11', and 16' below the surface

Thermocouples in ground temperature holes R-201, R-202, R-203 and R-204 are located at the gravel surface and at 6", 1', 1'-6", 2'-6", 4', 6', 10', and 15' below the surface.

Thermocouples in all other ground temperature holes in Area 2 are located at the pavement surface and at 6", 1', 1'-6", 2', 3', 4'-6", 6'-6", 10'-6", and 15'-6" below the surface.

Vertical movement observation points for unpaved sections are located the same as those shown in typical paving section except that the center point is not off-set.



SECTION C-C

SCALE: 1/2" = 1'-0"

DETAIL - A

0" 3" 6" 9" 12"

SCALE: 1 1/2" = 1'-0"

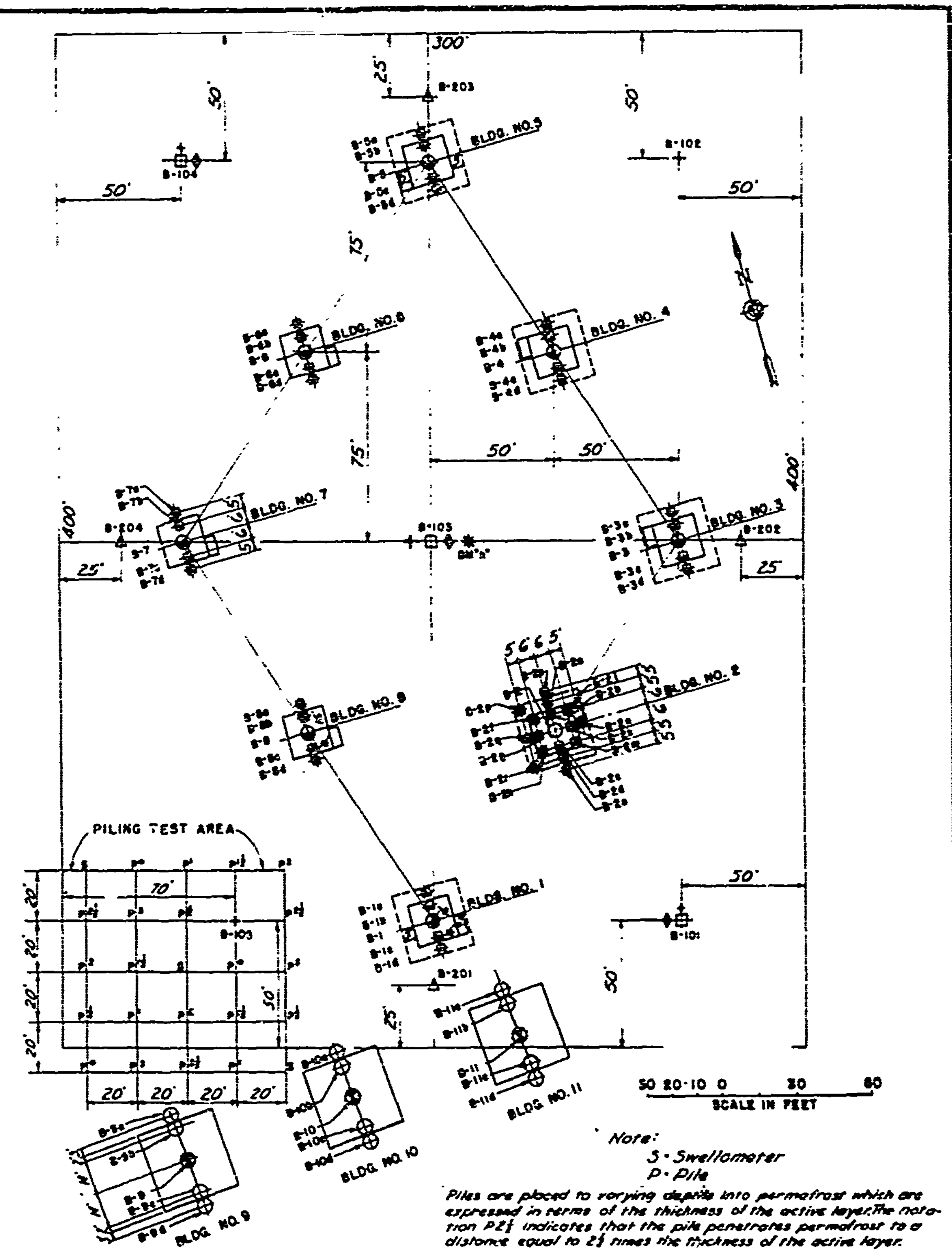
PERMAFROST INVESTIGATION

FIELD RESEARCH
FAIRBANKS, ALASKA
AREA NO. 2
RUNWAY FOUNDATION STUDIES

SCALE- AS SHOWN

CORPS OF ENGINEERS . ST. PAUL, MINN. MAY 1950

PLATE 13



LEGEND

- CORE BORING 40' DEEP
- CORE BORING 30' DEEP
- CORE BORING 20' DEEP
- CHURN DRILL HOLE 30' DEEP
- CHURN DRILL HOLE 20' DEEP

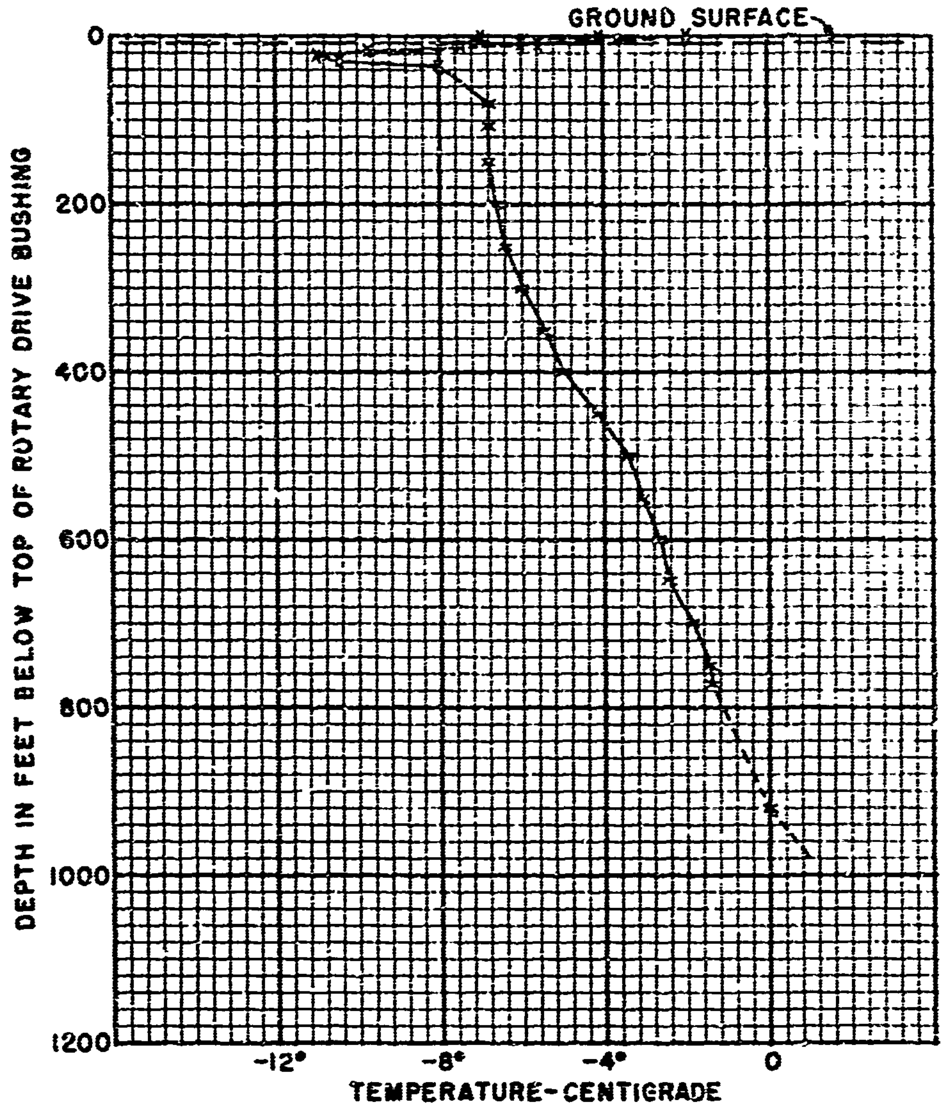
GROUND TEMPERATURE HOLES

- VERTICAL MOVEMENT OBSERVATION POINT
- BENCH MARK
- CHURN DRILL HOLE, 10' DEEP GROUND WATER WELL
- FROST OBSERVATION POINT

PERMAFROST INVESTIGATION
FIELD RESEARCH
FAIRBANKS, ALASKA
AREA NO. 3
PLAN

CORPS OF ENGINEERS ST PAUL, MINN. MAY [illegible]

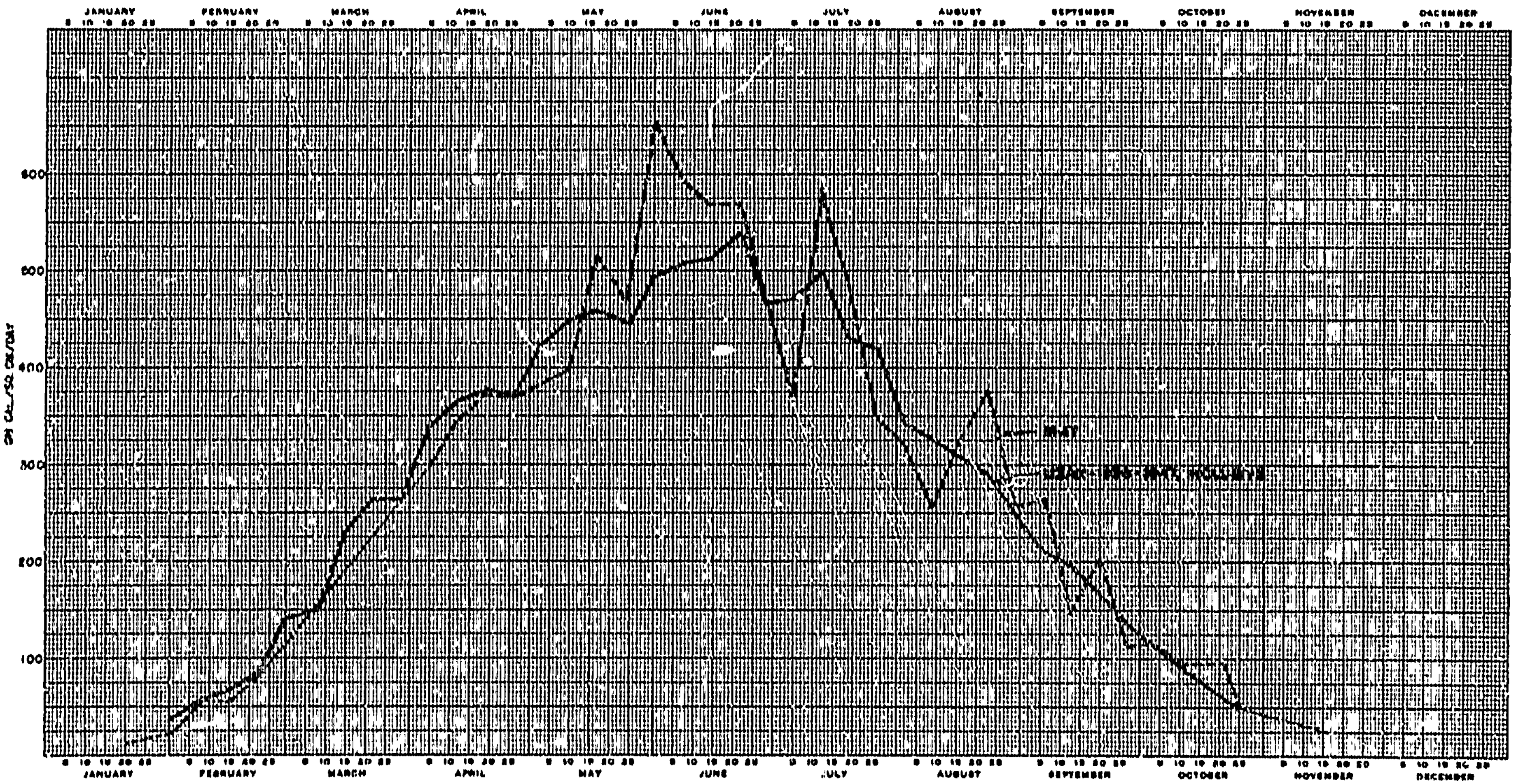
PLATE 14



NOTES:
BOTTOM OF CASING AT 635 FEET.
HOLE FILLED WITH OIL FROM 755 TO 775 FEET.
HOLE PLUGGED WITH ICE AT 775 FEET.
BOTTOM OF ICE AT 920 FEET.
TOTAL DEPTH OF HOLE 1,816 FEET.
TEMPERATURE TAKEN BY J.H. FOLK 27-30 MAY 1946.
HOLE DRILLED IN OIL EXPLORATORY WORK BY DEPARTMENT OF THE NAVY.

PERMAFROST INVESTIGATION
UMIAT, ALASKA
WELL NO. 1
GROUND TEMPERATURE GRADIENT
CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

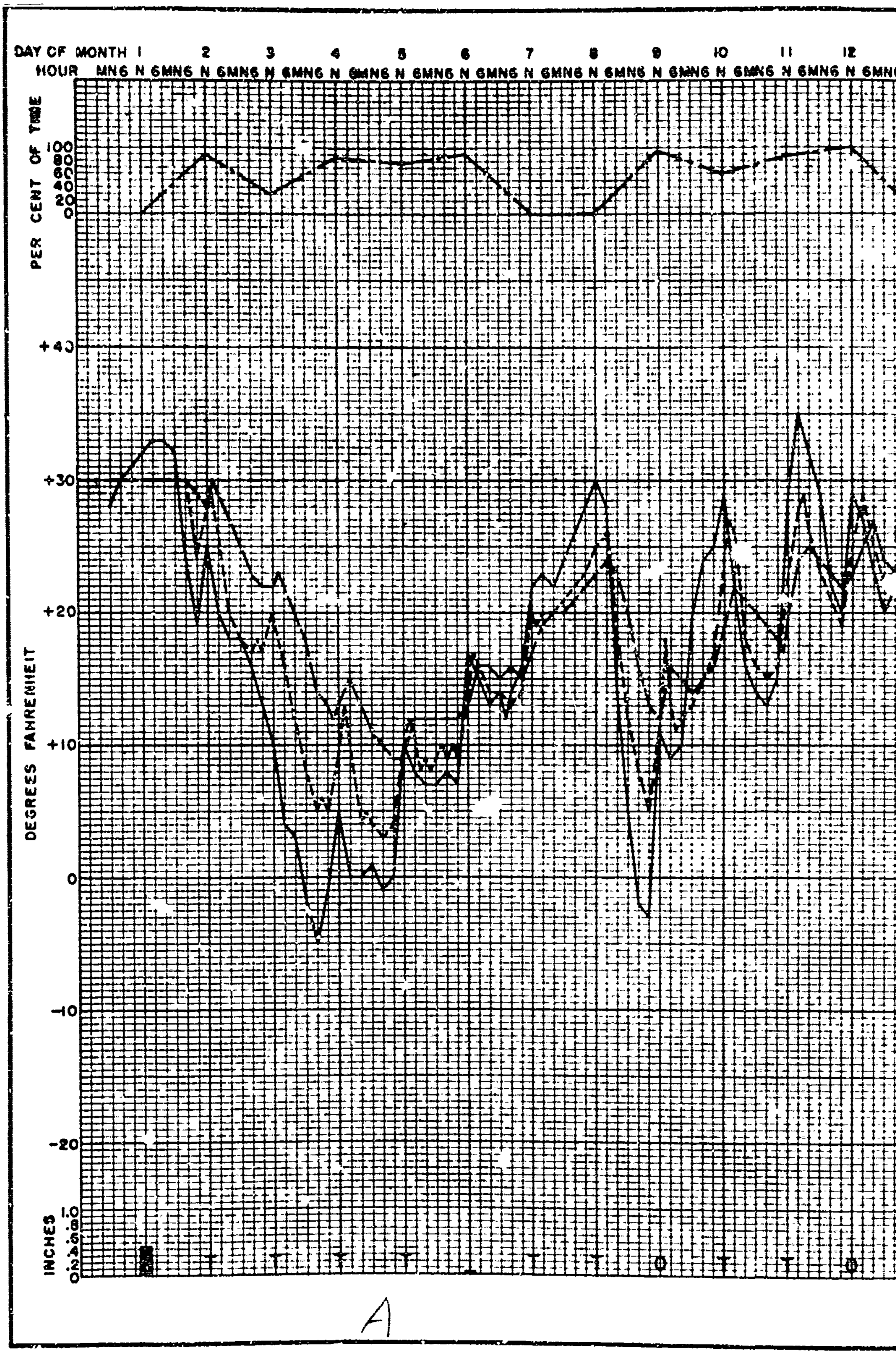
PLATE 15



PERMAFROST INVESTIGATION
FAIRBANKS, ALASKA
MEAN DAILY SOLAR AND
SKY RADIATION RECEIVED

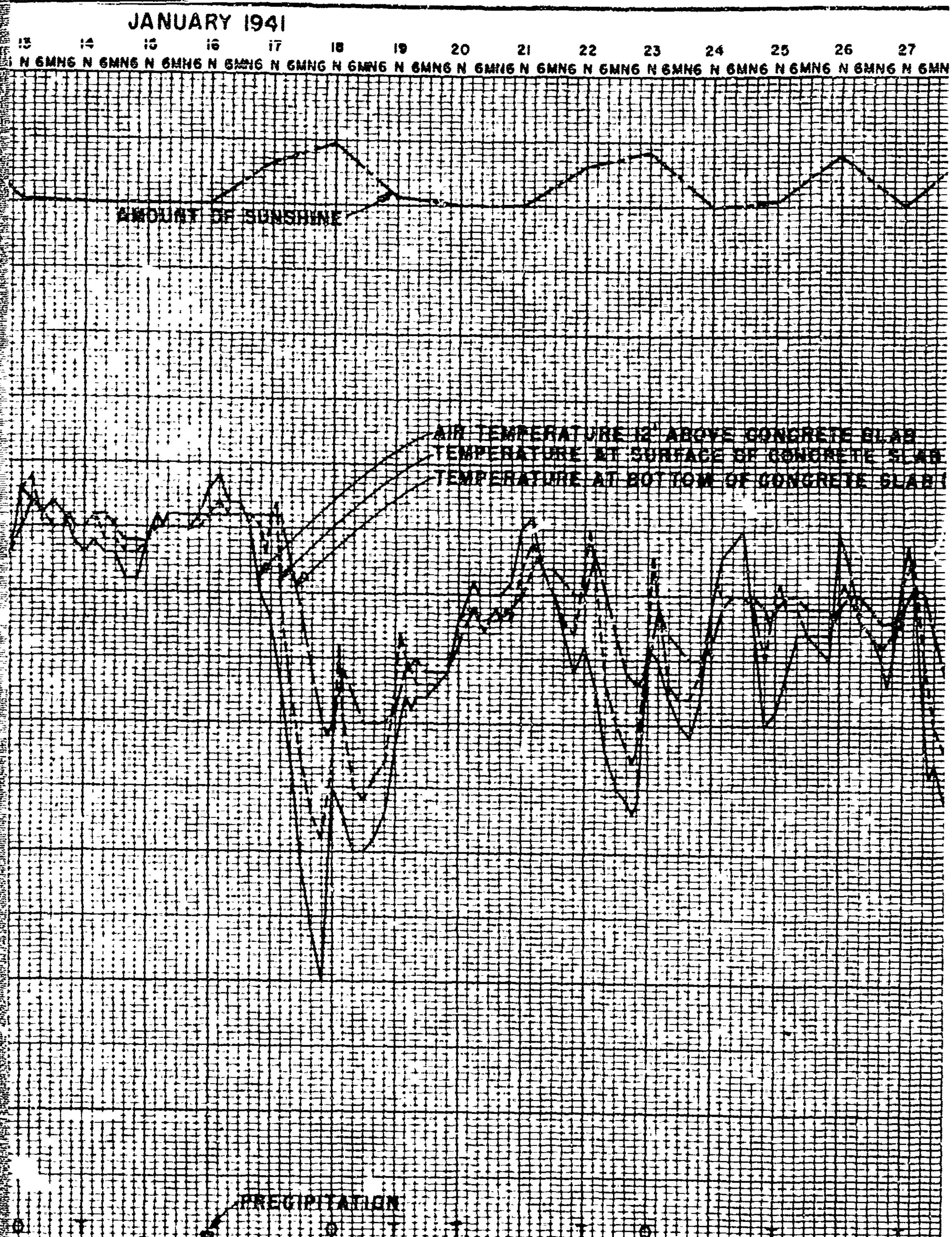
CORPS OF ENGINEERS, ST PAUL MINN   MAY 1950

PLATE 16



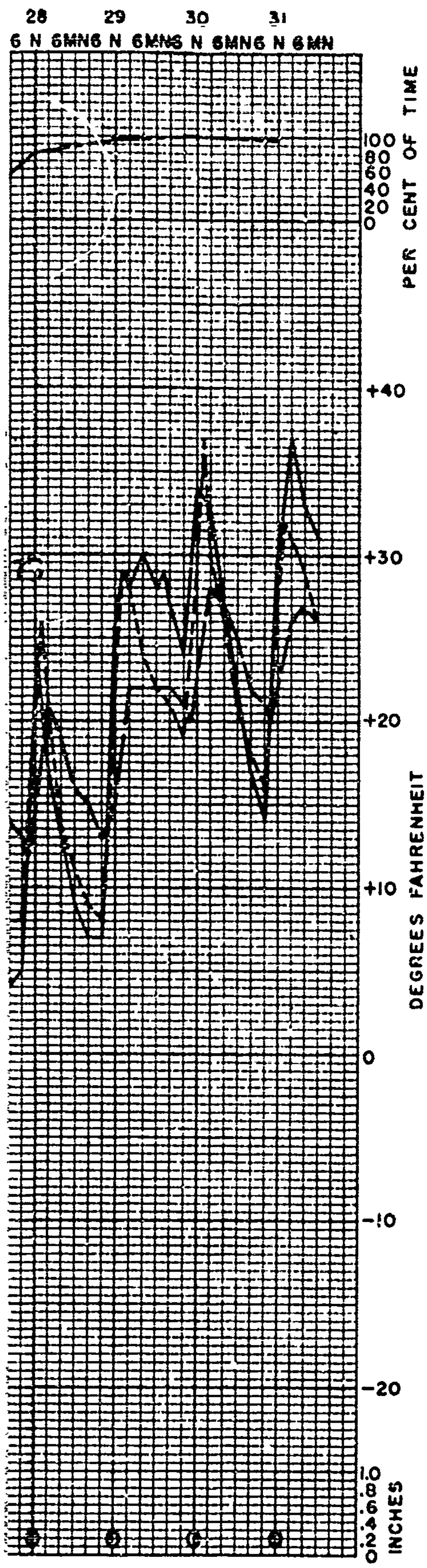
DAY OF MONTH 1 2 3 4 5 6 7 8 9 10 11 12
HOUR MN 6 N 6 MN 6 N 6 MN 6 N 6 MN
PER CENT OF TIME
100 80 60 40 20 0
DEGREES FAHRENHEIT
+40
+30
+20
+10
0
-10
-20
INCHES
1.0 .8 .6 .4 .2 0

A



JANUARY 1941
13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN
AMOUNT OF SUNSHINE
AIR TEMPERATURE 12" ABOVE CONCRETE SLAB
TEMPERATURE AT SURFACE OF CONCRETE SLAB
TEMPERATURE AT BOTTOM OF CONCRETE SLAB
PRECIPITATION

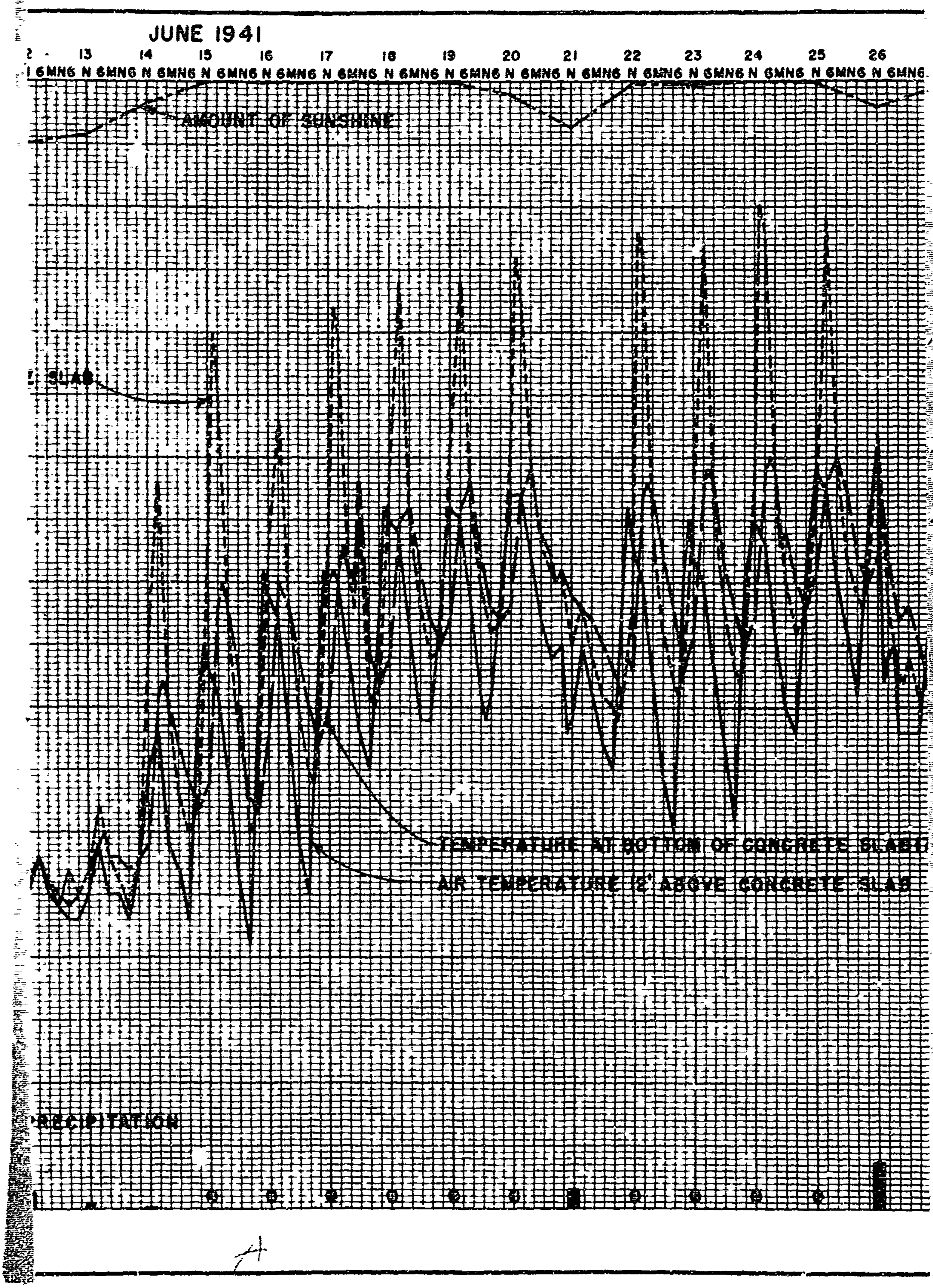
B



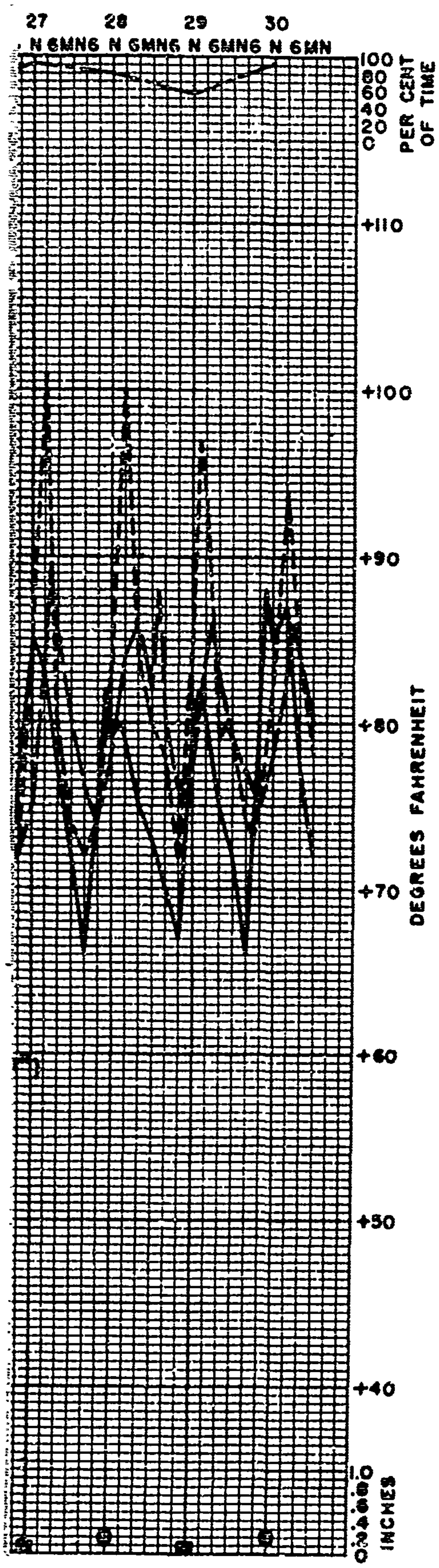
PERMAFROST INVESTIGATION
MINNESOTA HIGHWAY DEPARTMENT
TEST SLAB
AIR AND CONCRETE
PAVEMENT TEMPERATURES
JANUARY 1941

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 17


JUNE 1941
13
14
15
16
17
18
19
20
21
22
23
24
25
26
AMOUNT OF SUNSHINE
SLAB
TEMPERATURE AT BOTTOM OF CONCRETE SLAB
AIR TEMPERATURE 12' ABOVE CONCRETE SLAB
RECIPITATION

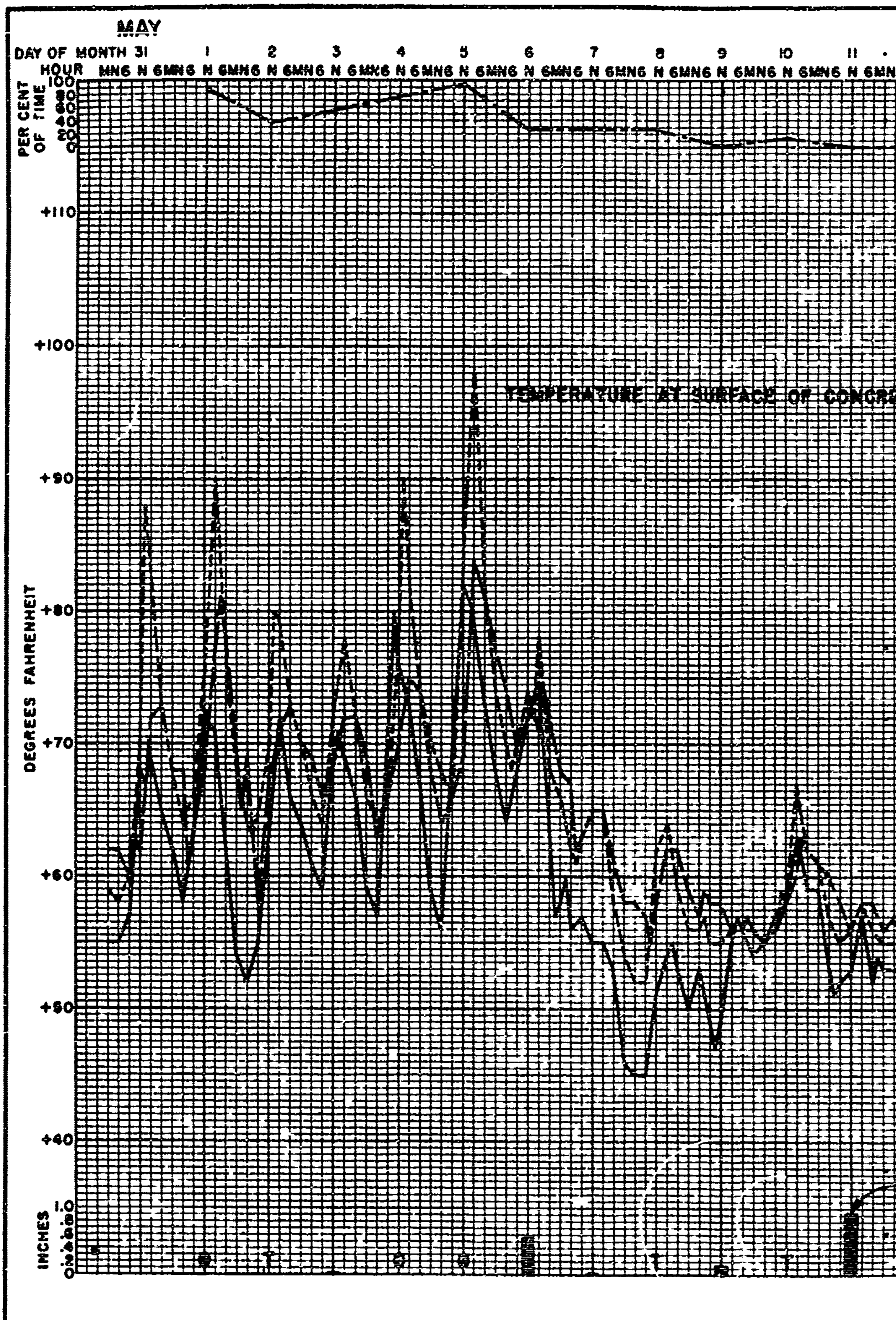
4



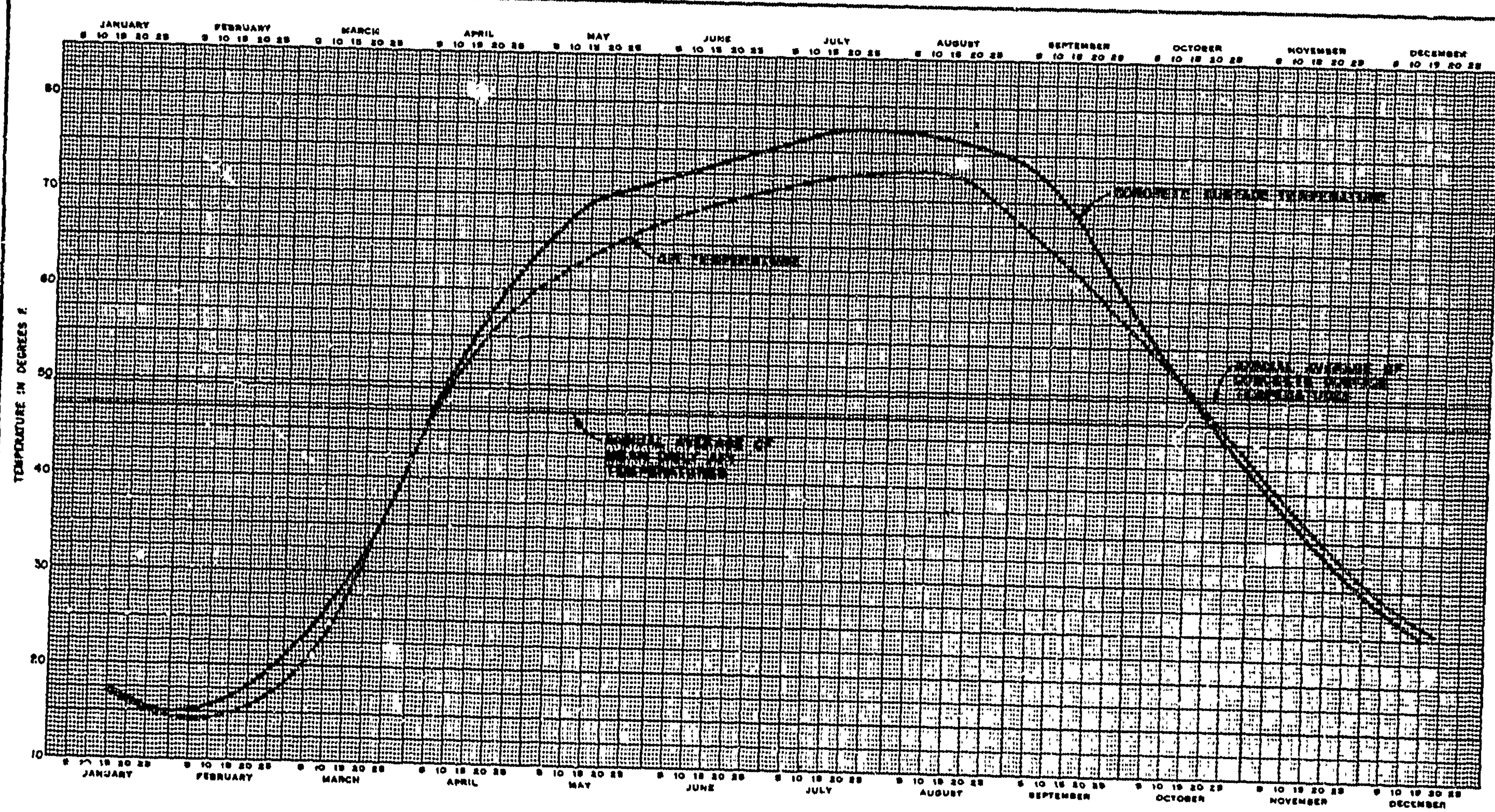
PERMAFROST INVESTIGATION
MINNESOTA HIGHWAY DEPARTMENT
TEST SLAB
AIR AND CONCRETE
PAVEMENT TEMPERATURES
JUNE 1941

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 18



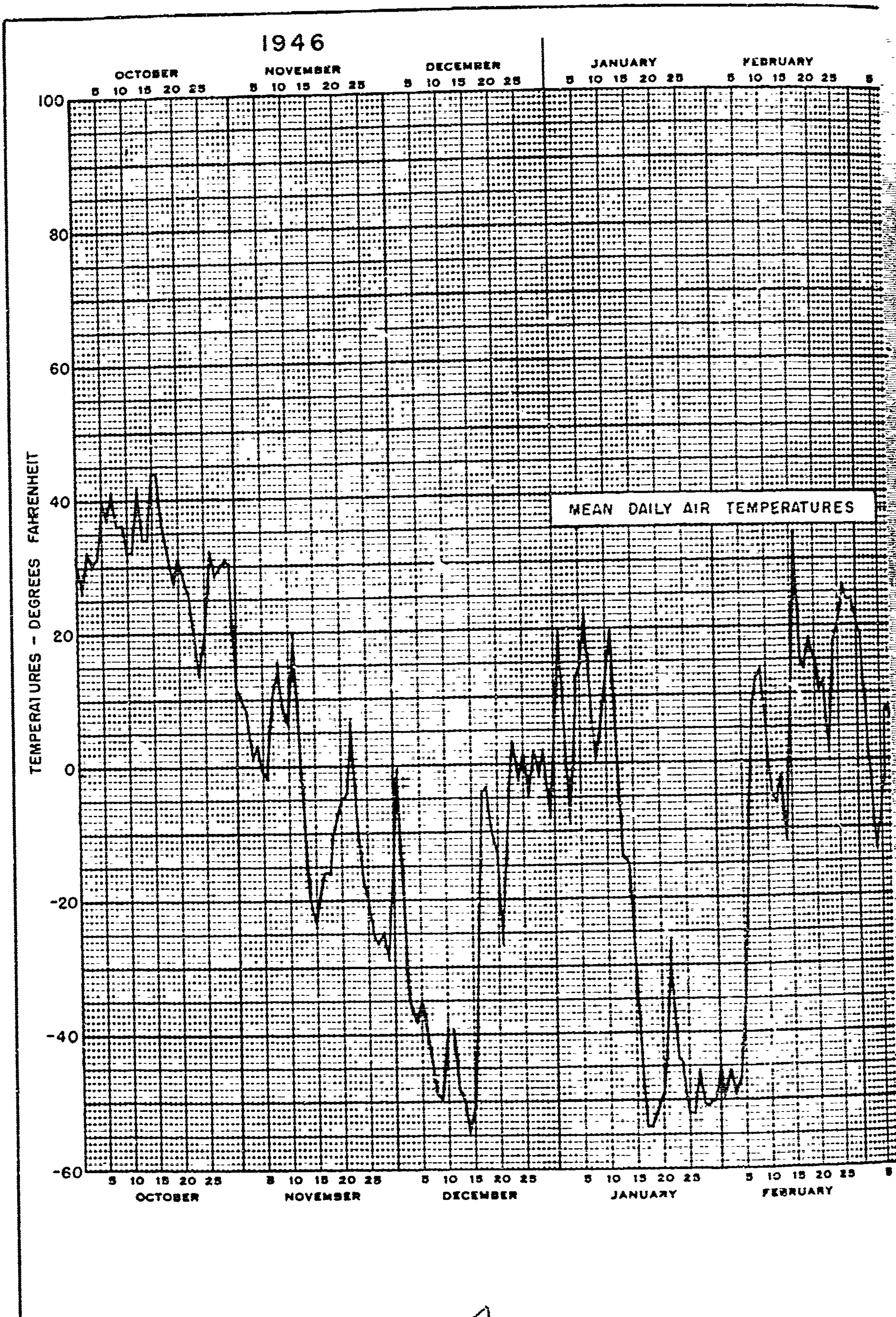
MAY
DAY OF MONTH 31 1 2 3 4 5 6 7 8 9 10 11
HOUR MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6 N 6MN6
PER CENT OF TIME
100
80
60
40
20
0
+110
+100
+90
+80
+70
+60
+50
+40
DEGREES FAHRENHEIT
TEMPERATURE AT SURFACE OF CONCRE
INCHES
1.0
0



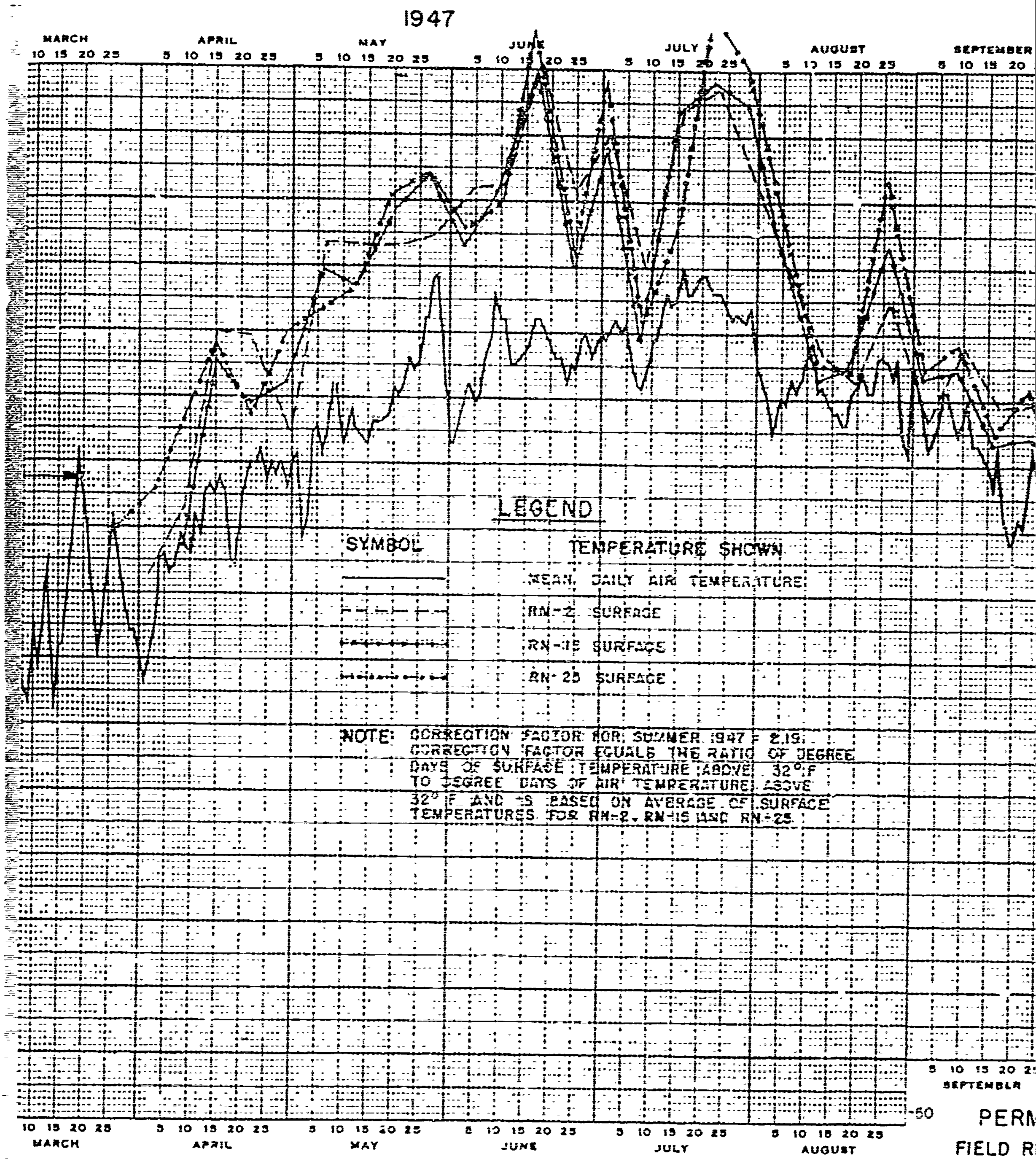
PERMAFROST INVESTIGATION
MINNESOTA HIGHWAY DEPARTMENT
TEST SLAB
AVERAGE ANNUAL AND MONTHLY AIR
AND CONCRETE SURFACE TEMPERATURES
1941

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 19



1946
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
5 10 15 20 25
100
80
60
40
20
0
-20
-40
-60
TEMPERATURES - DEGREES FAHRENHEIT
MEAN DAILY AIR TEMPERATURES
A

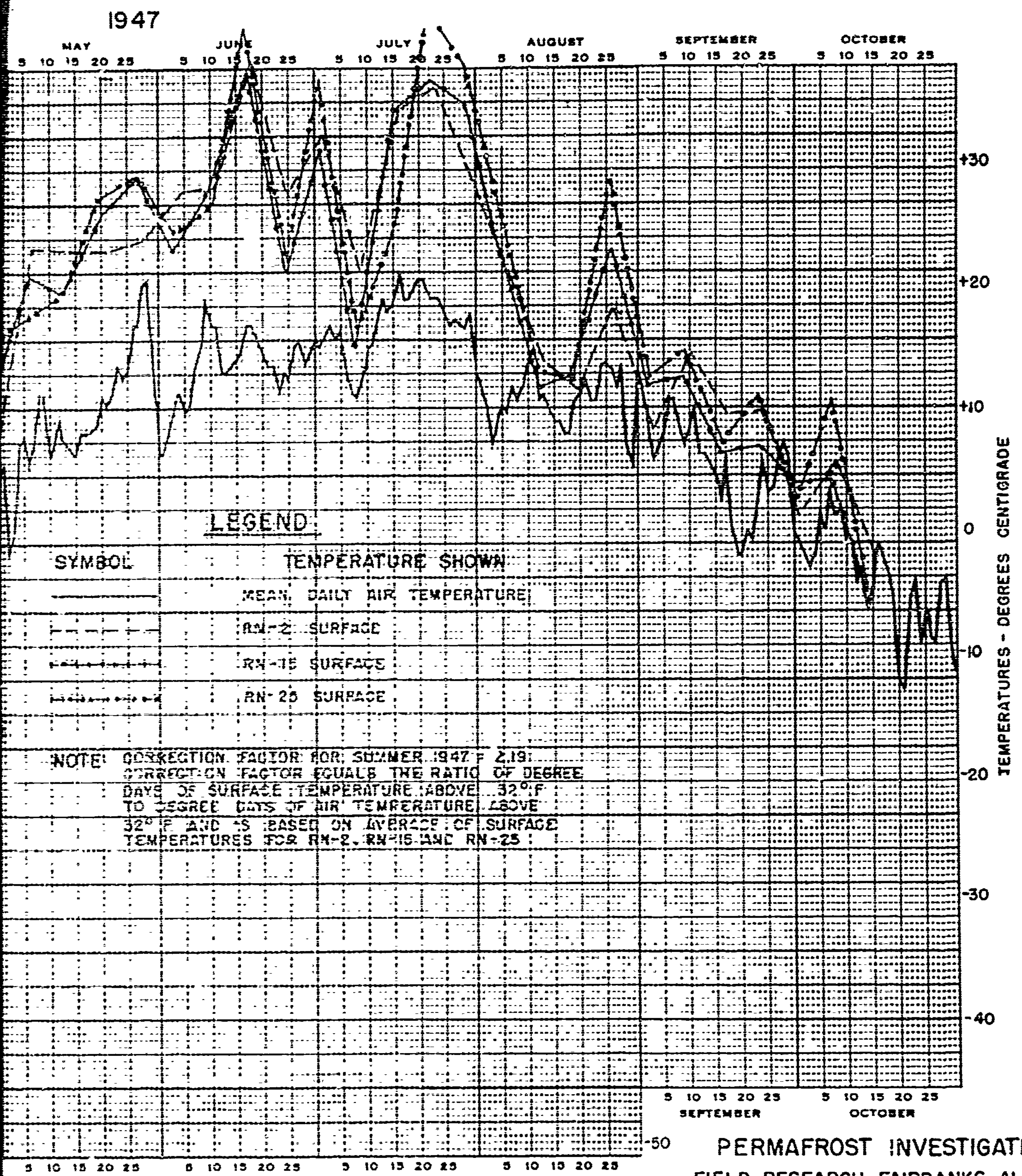


PERM

FIELD R

AIR AND B

CORPS OF EN



PERMAFROST INVESTIGATION

FIELD RESEARCH-FAIRBANKS, ALASKA

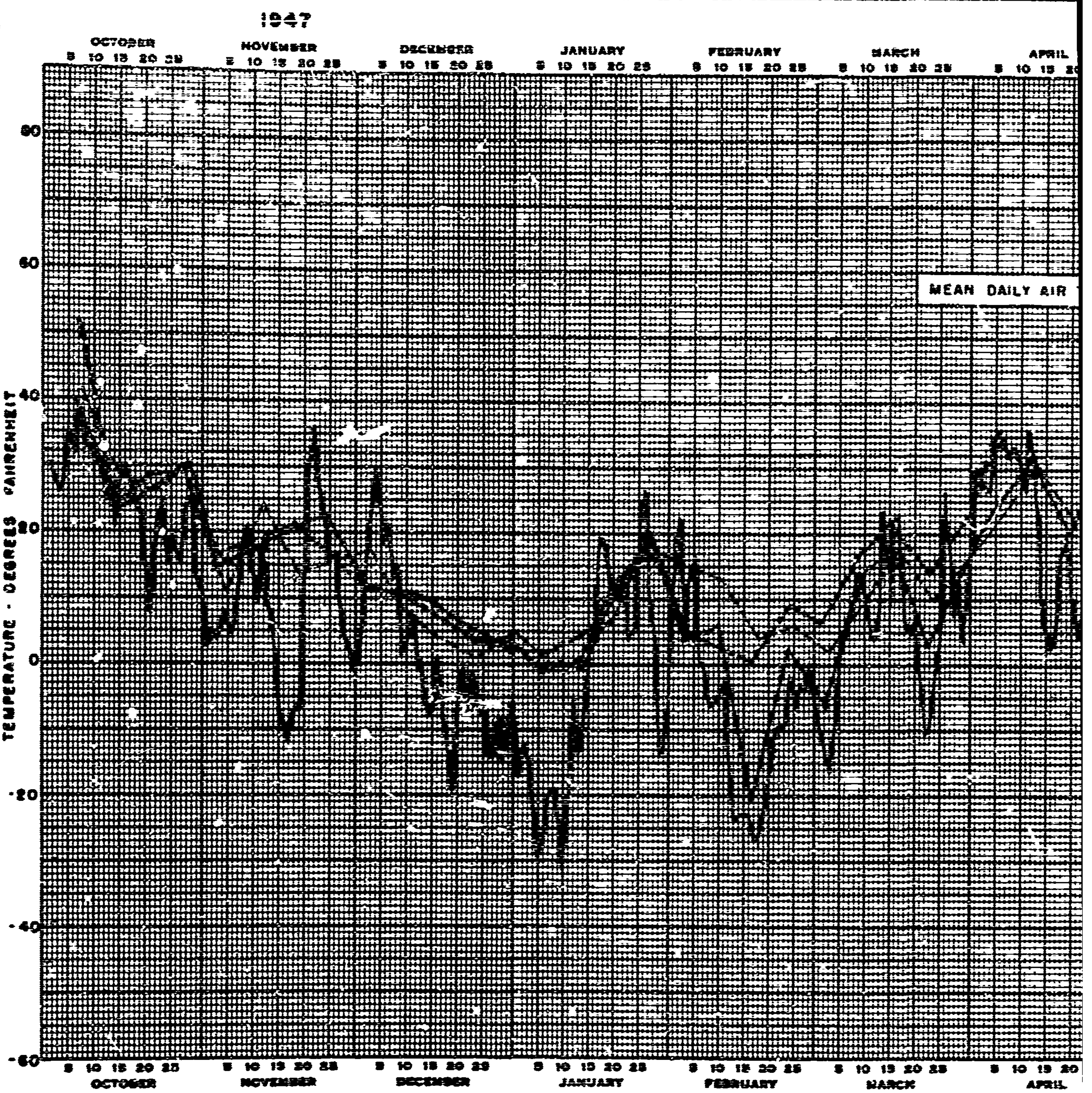
AREA NO. 2

AIR AND BITUMINOUS SURFACE TEMPERATURES

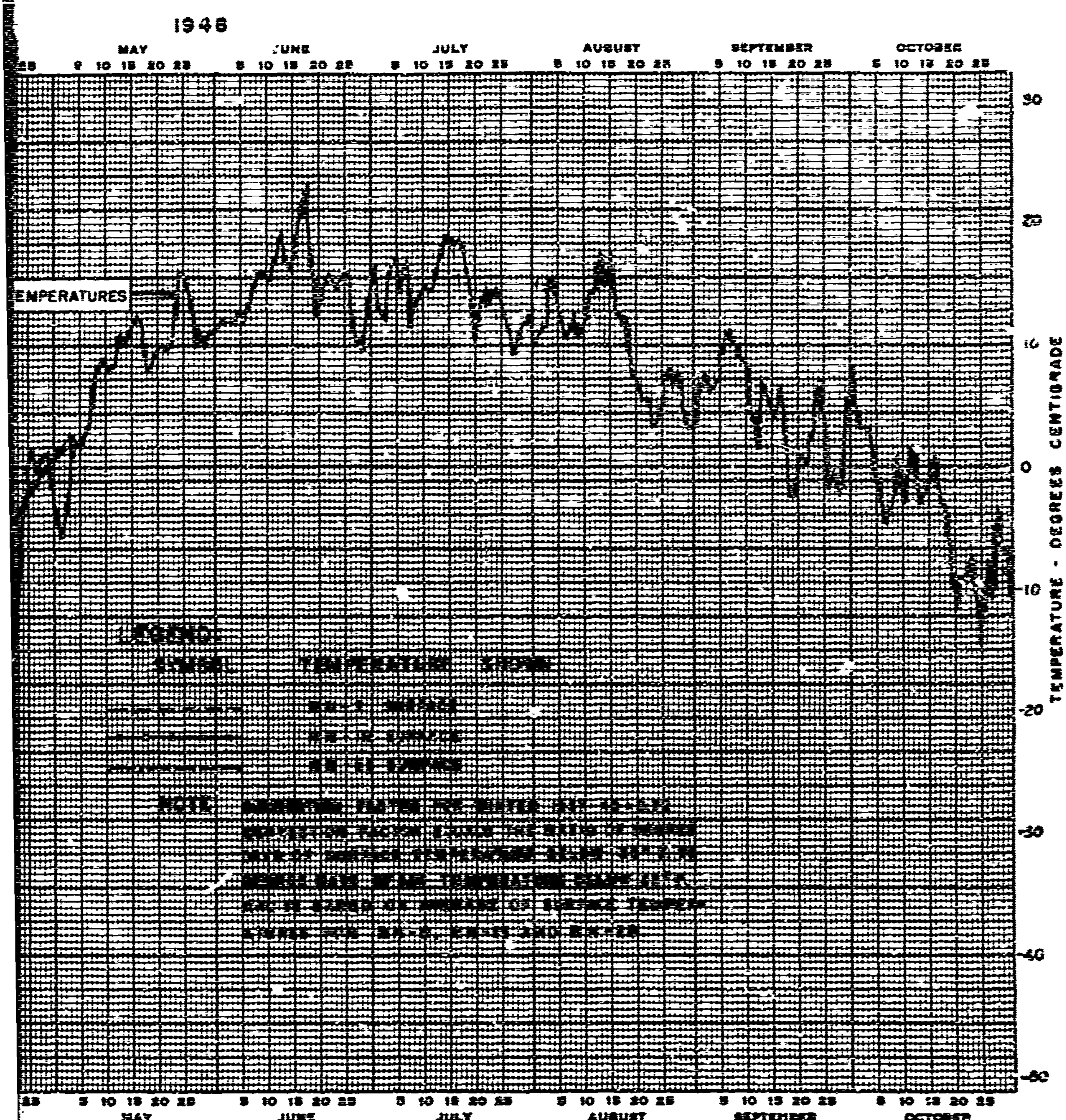
SUMMER-1947

CORPS OF ENGINEERS ST. PAUL, MINN. MAY 1950

PLATE 20



1947
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
5 10 15 20 25
TEMPERATURE - DEGREES FAHRENHEIT
80
60
40
20
0
-20
-40
-60
MEAN DAILY AIR



PERMAFROST INVESTIGATION

FIELD RESEARCH - FAIRBANKS, ALASKA

AREA NO. 2

AIR AND

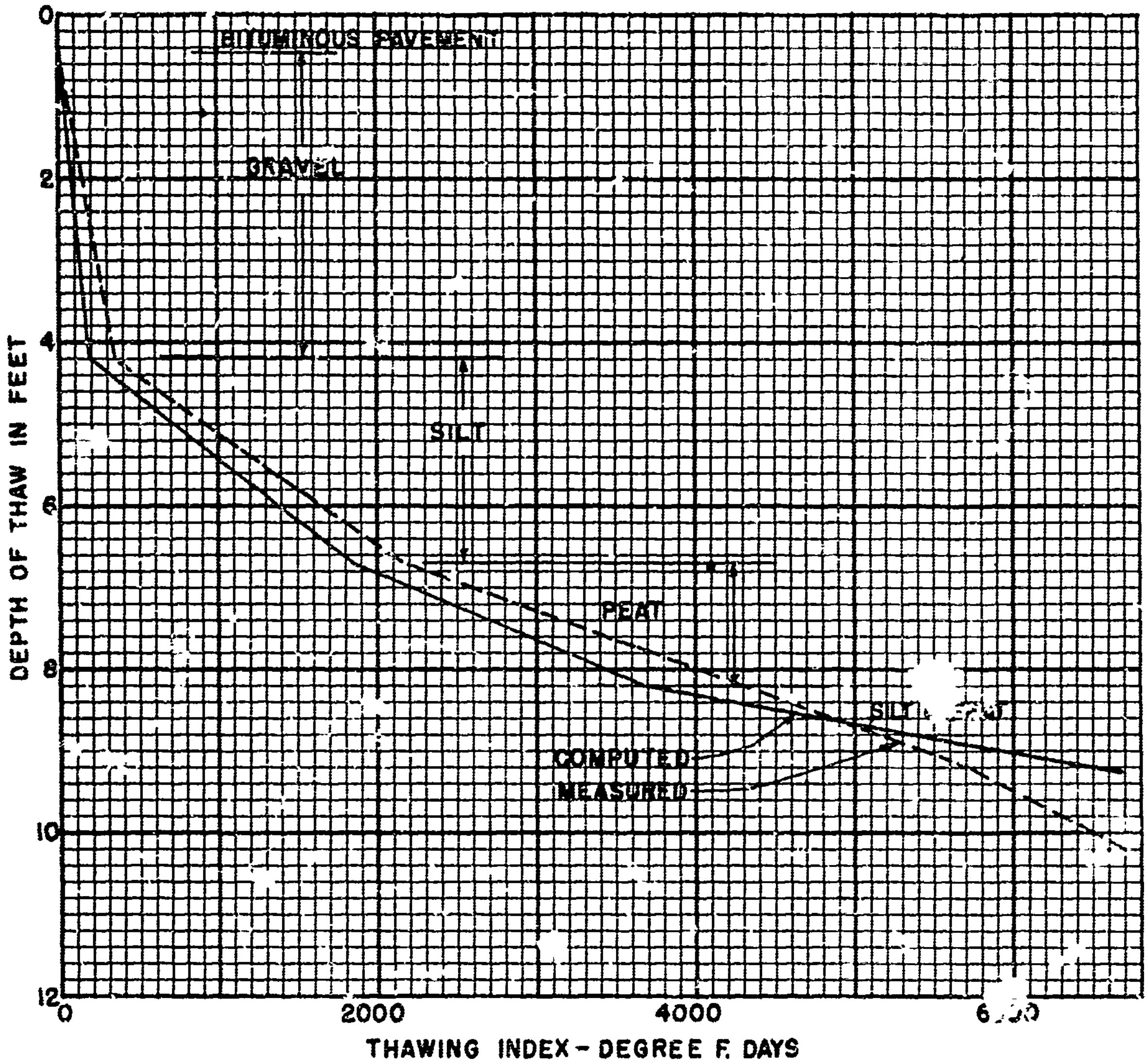
BITUMINOUS SURFACE TEMPERATURES

WINTER 1947-48

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

B

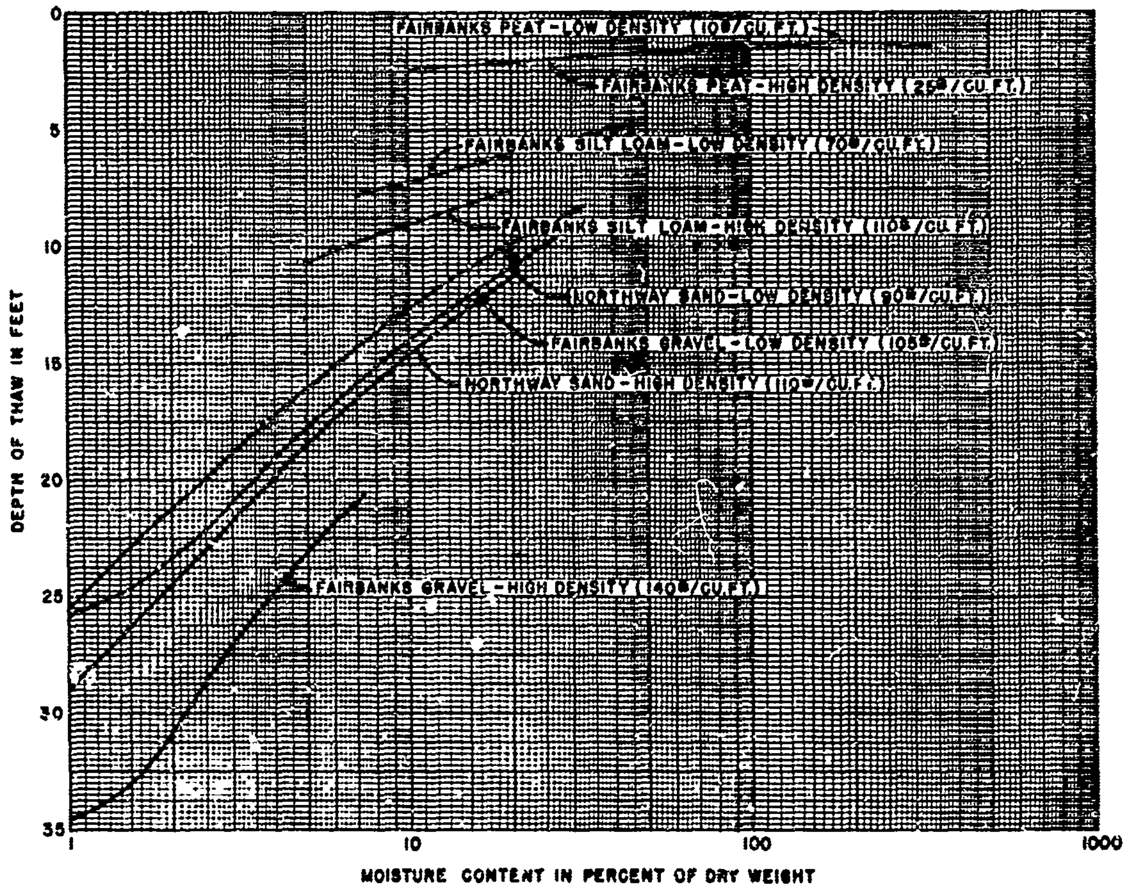
PLATE 21



PERMAFROST INVESTIGATION
FAIRBANKS RESEARCH AREA
RUNWAY TEST SECTION RN-4
DEPTH OF THAW

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 22



NOTE:
FORMULA FOR DEPTH OF THAW IN SINGLE LAYER OF UNIFORM SOIL IS

$$h = \sqrt{\frac{24\ CI \times 2k}{L}} \quad \text{WHERE}$$

h = DEPTH OF THAW IN FEET.
I = THAWING INDEX IN DEGREE DAYS.
C = CONSTANT TO CORRECT THAWING INDEX FOR SURFACE CONDITIONS.
k = COEFFICIENT OF THERMAL CONDUCTIVITY.
L = 1.434 x DENSITY x MOISTURE CONTENT.

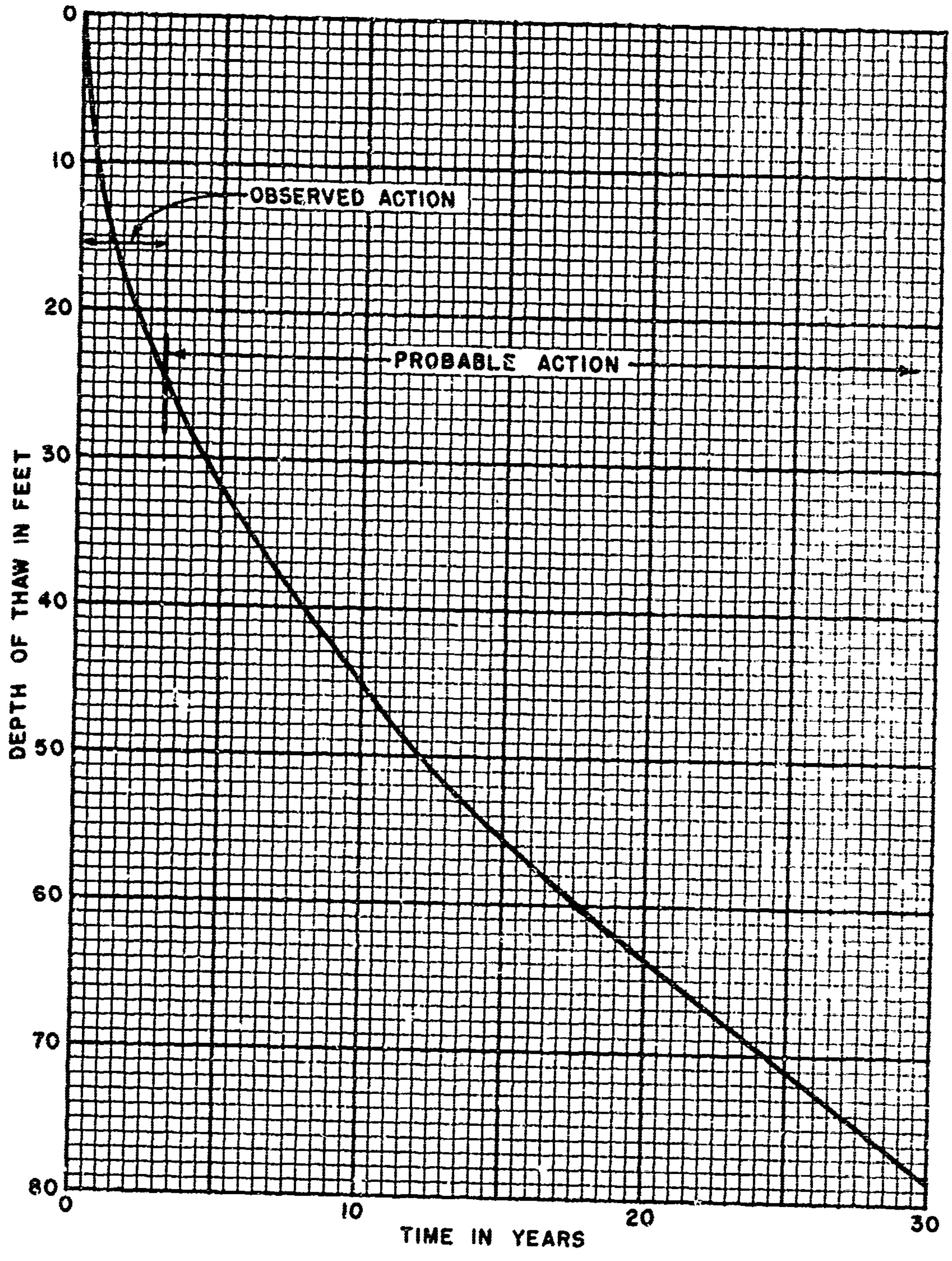
FOR THIS GRAPH, THAWING INDEX TAKEN EQUAL TO 3000 AND FACTOR "C" AS FOLLOWS.

C	SOIL
0.37	PEAT
1.22	FAIRBANKS SILT LOAM
2.00	FAIRBANKS GRAVEL
2.00	NORTHWAY SAND

PERMAFROST INVESTIGATION
THEORETICAL STUDIES
COMPUTED DEPTH OF THAW IN PEAT, SILT LOAM, SAND, AND GRAVEL

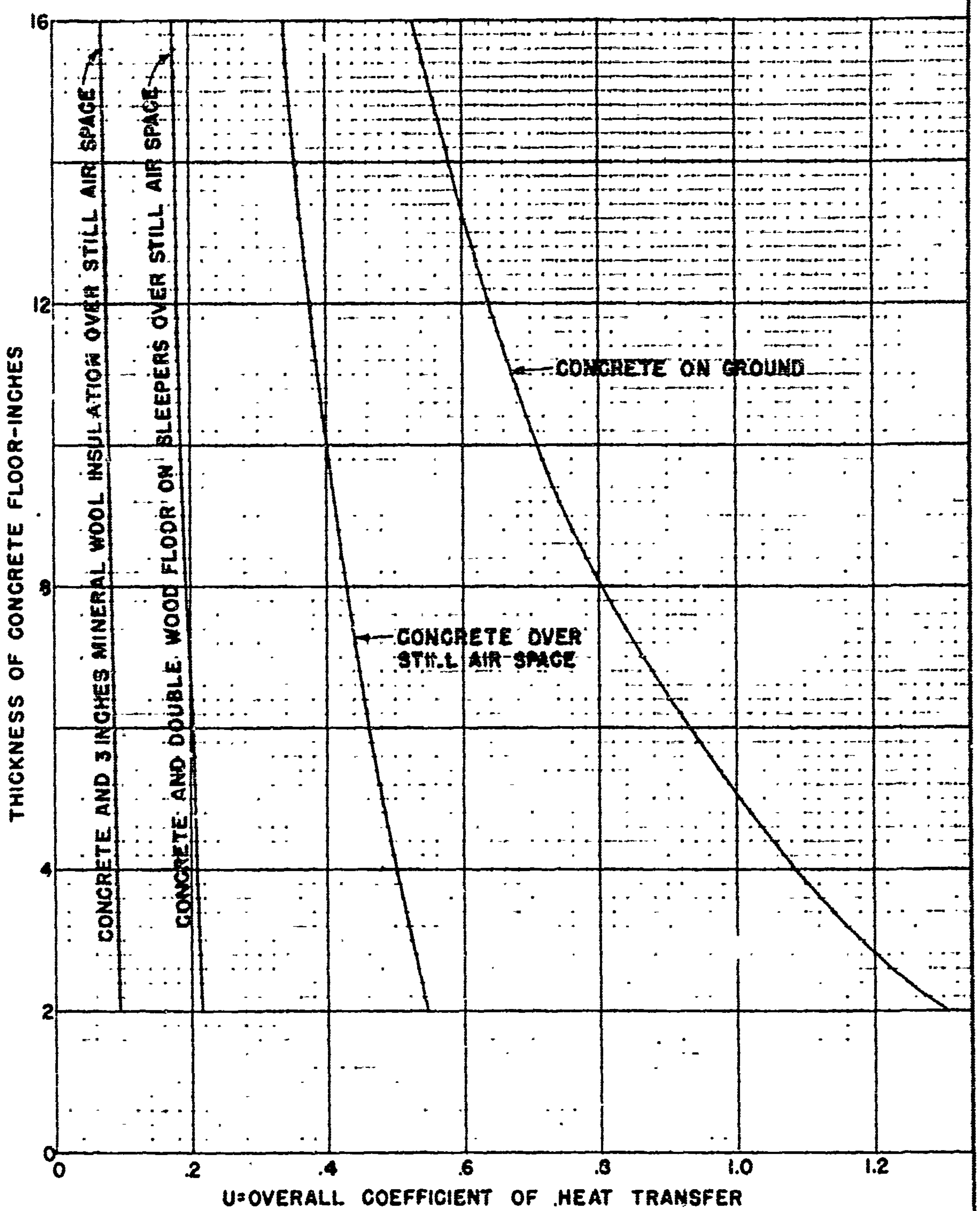
CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 23



PERMAFROST INVESTIGATION
NORTHWAY AIRFIELD, ALASKA
PROBABLE DEPTH OF THAW UNDER HANGAR
CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

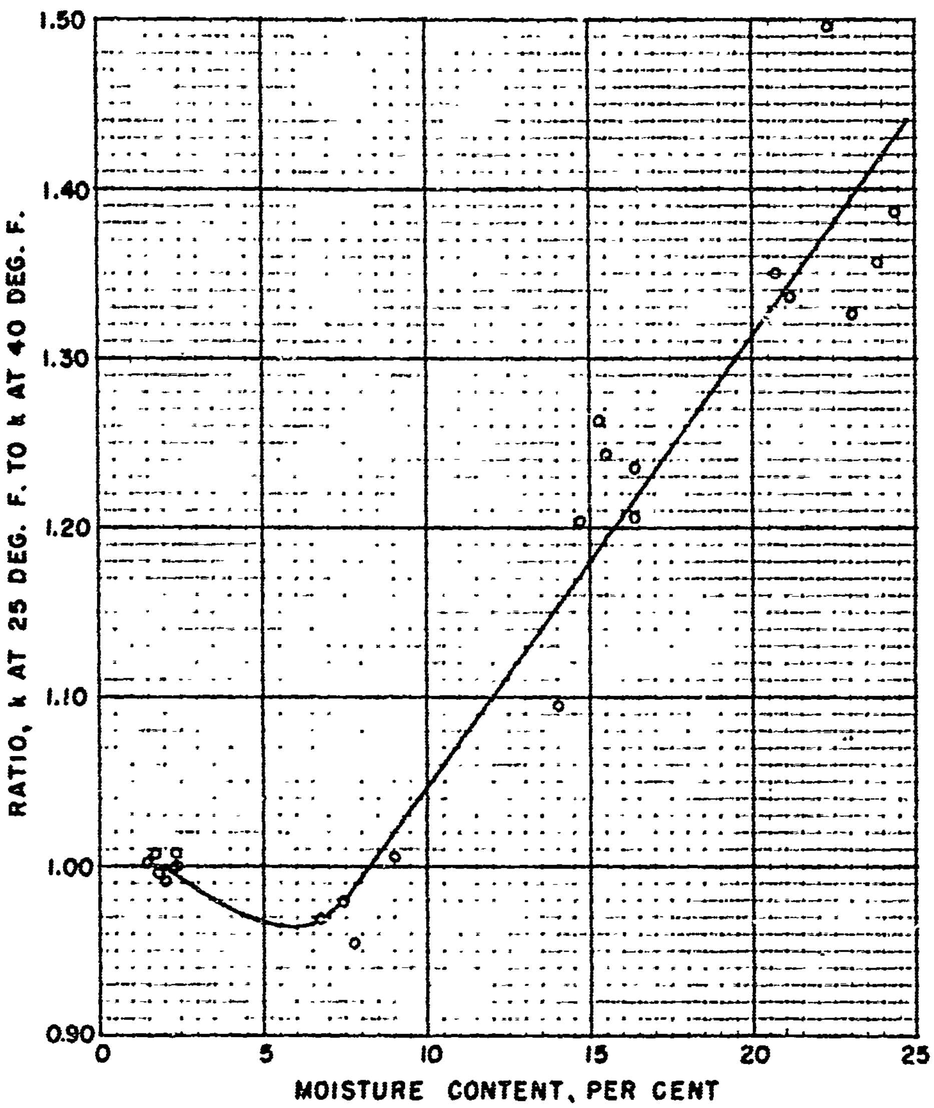
PLATE 24



PERMAFROST INVESTIGATION
COMPUTED HEAT TRANSFER
THROUGH CONCRETE FLOOR OF
LARGE BUILDING

CORPS OF ENGINEERS, ST. PAUL, MINN MAY 1950

PLATE 25



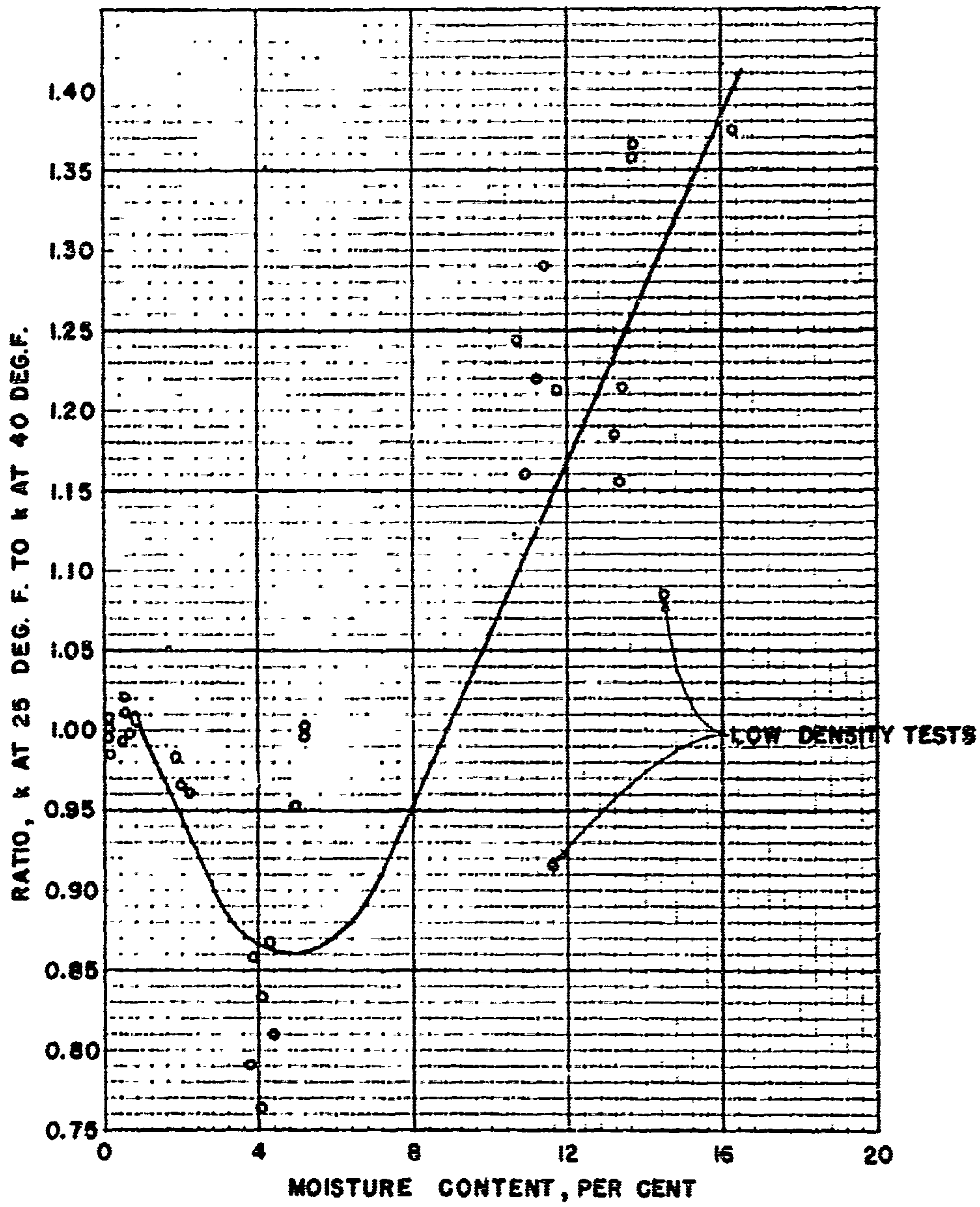
PERMAFROST INVESTIGATION

LABORATORY RESEARCH, UNIVERSITY OF MINN.

RATIO OF CONDUCTIVITY OF SILT LOAM SOILS BELOW TO CONDUCTIVITY ABOVE FREEZING POINT

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 26



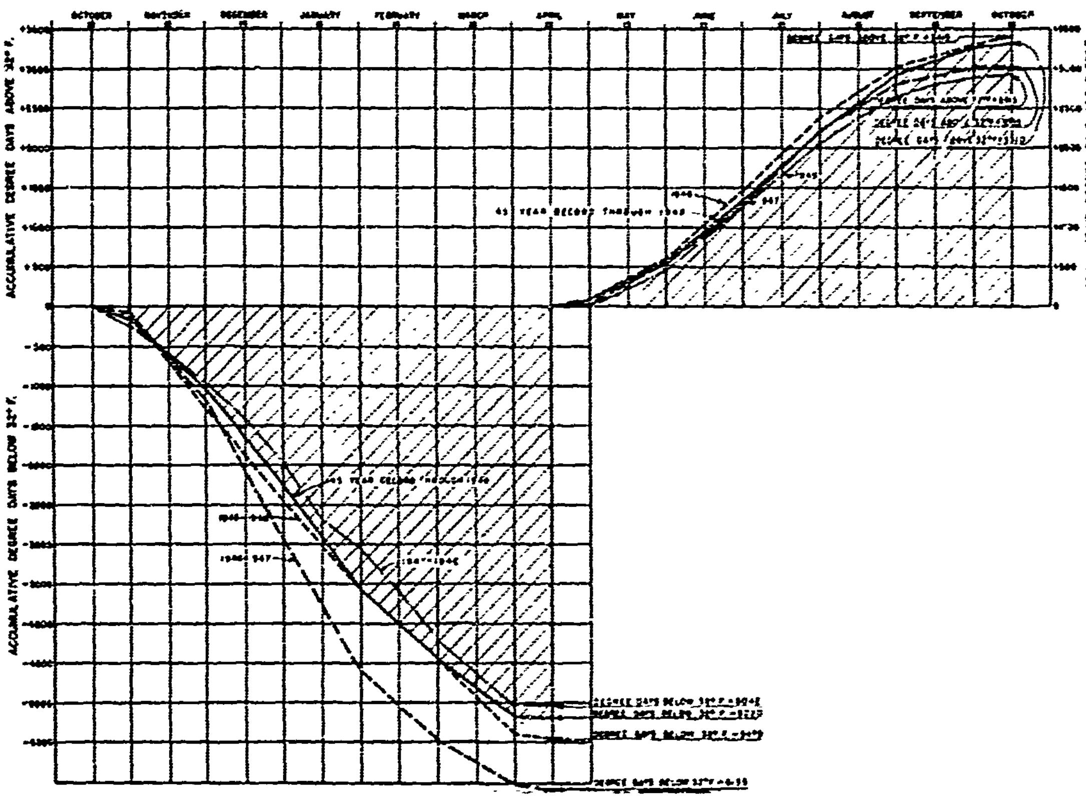
PERMAFROST INVESTIGATION

LABORATORY RESEARCH, UNIVERSITY OF MINN.

RATIO OF CONDUCTIVITY OF SAND SOILS BELOW TO CONDUCTIVITY ABOVE FREEZING POINT

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 27



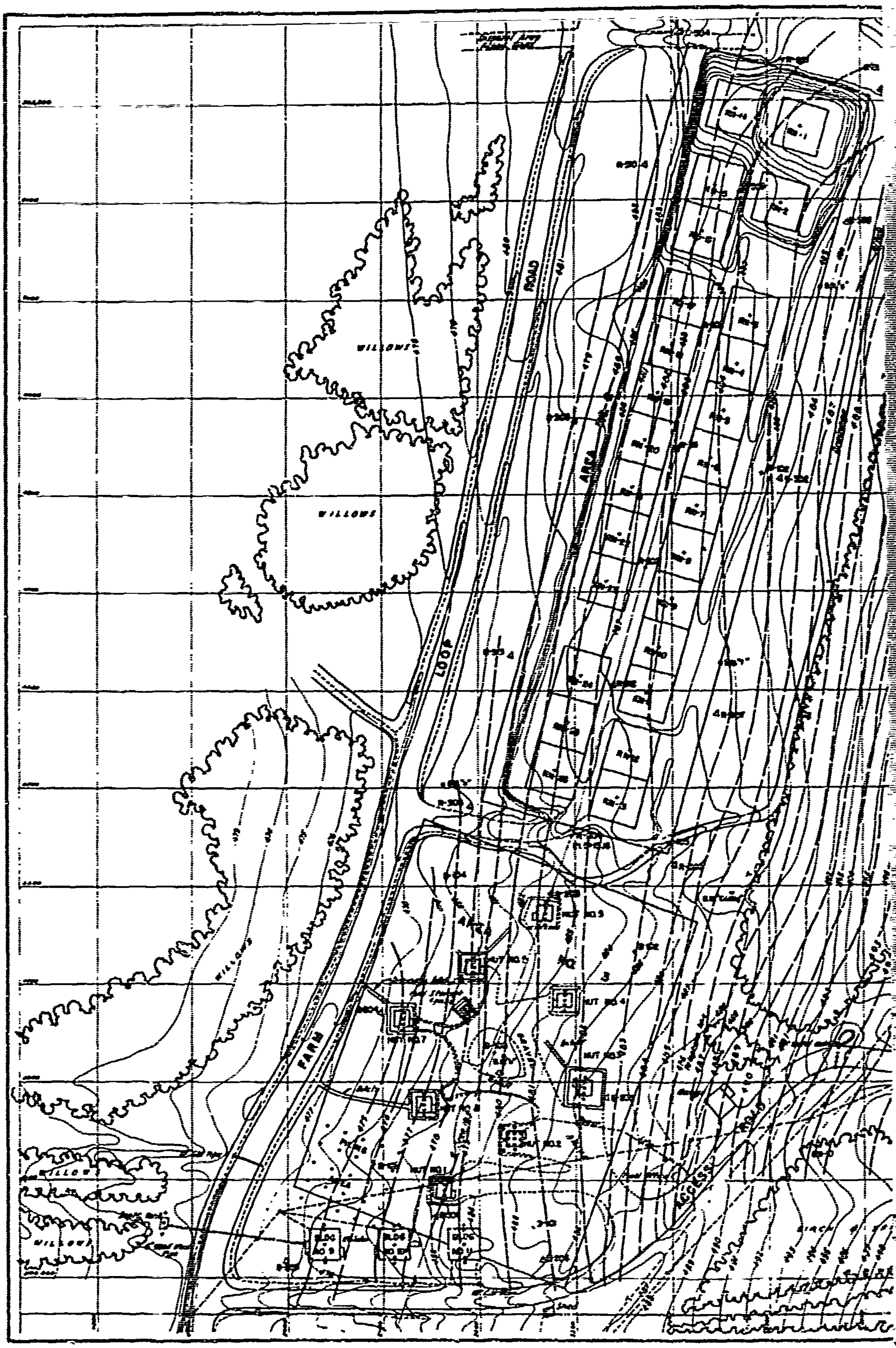
NOTE:

MEAN ANNUAL TEMPERATURE = 26.1° F. (45 YEAR RECORD).

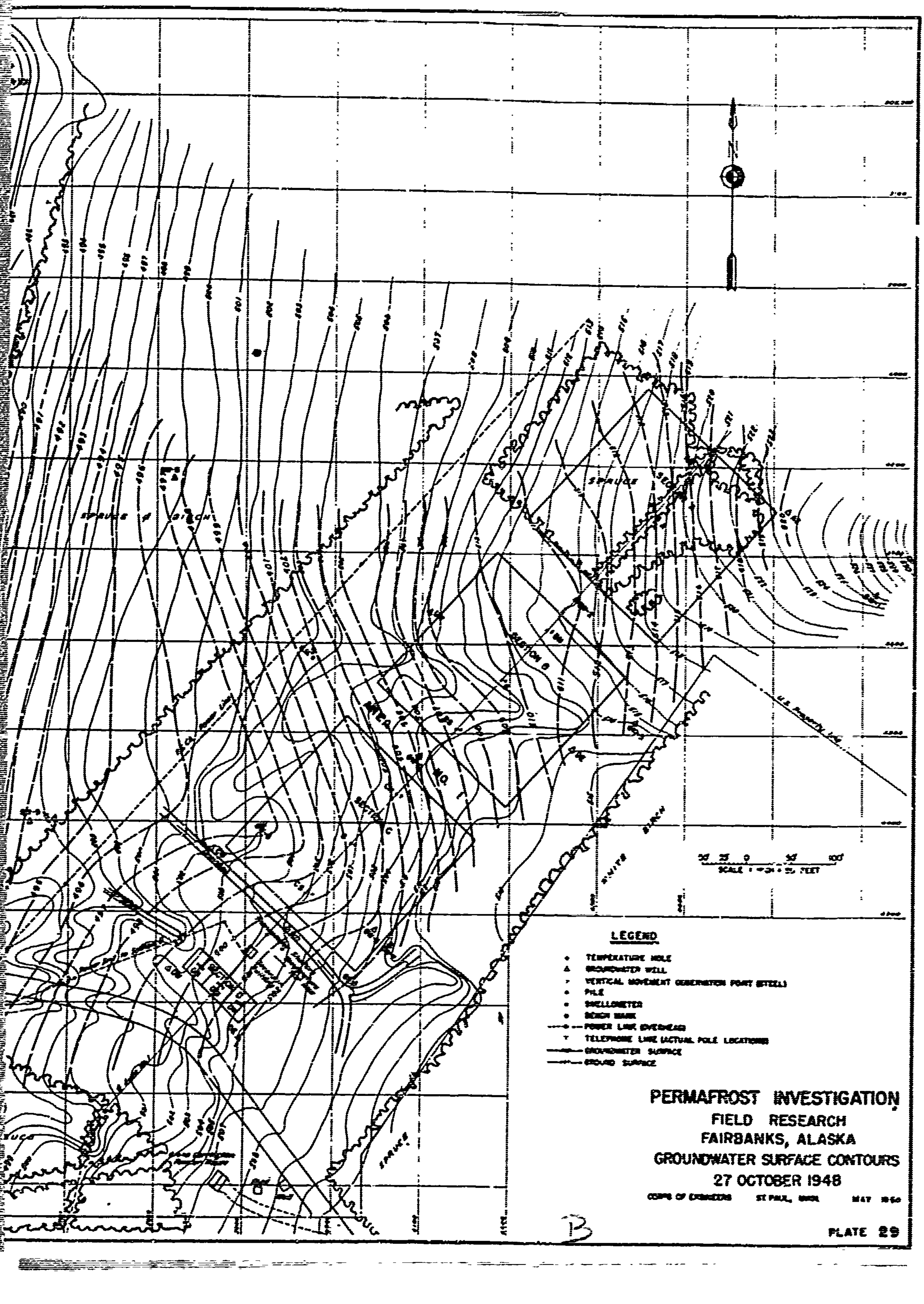
DATA COMPUTED FROM ALASKA SECTION "CLIMATOLOGICAL DATA" BY U. S. WEATHER BUREAU USING MEAN MONTHLY TEMPERATURES.

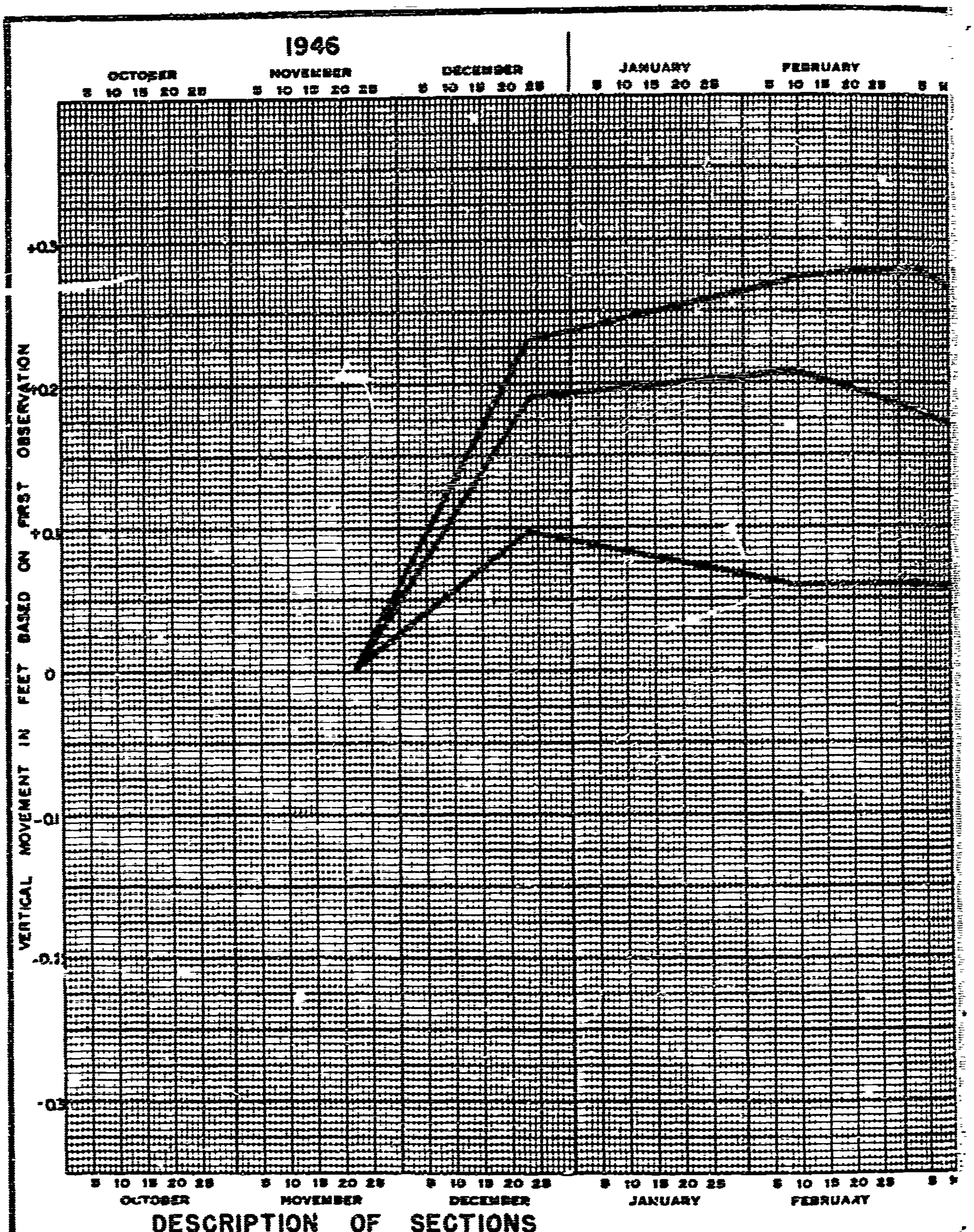
PERMAFROST INVESTIGATION
METEOROLOGICAL STUDIES
U. S. W. B. WEATHER STATION
WEEKS FIELD - FAIRBANKS, ALASKA
DEGREE DAYS ABOVE & BELOW 32° F.
CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 23



A


SPRUCE & BIRCH
SPRUCE
SECTION B
SECTION C
U.S. Property Line
LEGEND
TEMPERATURE HOLE
GROUNDWATER WELL
PILE
PERMAFROST INVESTIGATION
FIELD RESEARCH
FAIRBANKS, ALASKA
GROUNDWATER SURFACE CONTOURS
27 OCTOBER 1948
PLATE 29



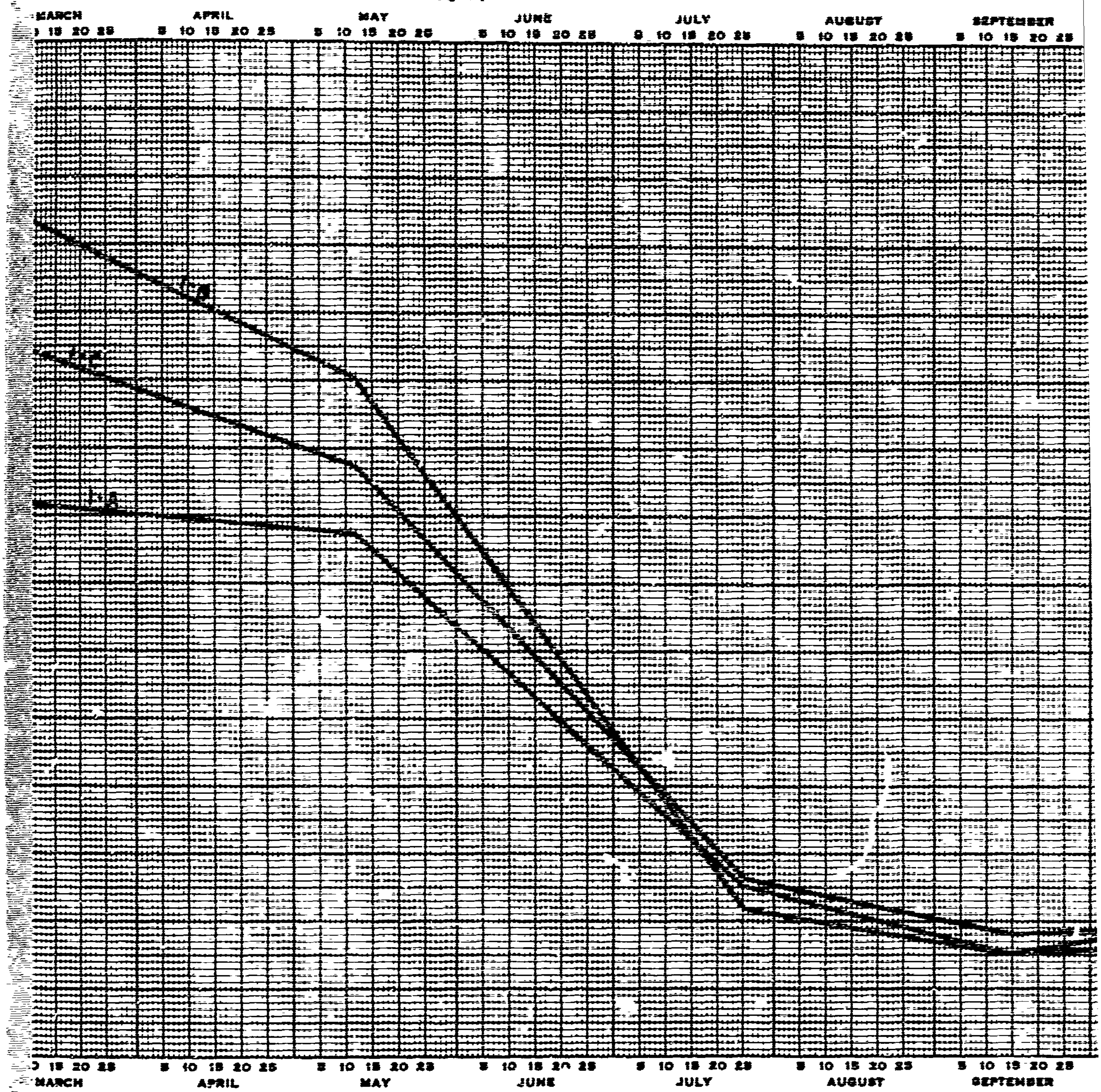
DESCRIPTION OF SECTIONS

AREA NO. 1

SECTION 1-A, NATURAL UNDISTURBED SECTION
" 1-B, TREES AND BRUSH ONLY REMOVED
" 1-C, ALL VEGETATION AND SOIL REMOVED TO 12" DEPTH

A

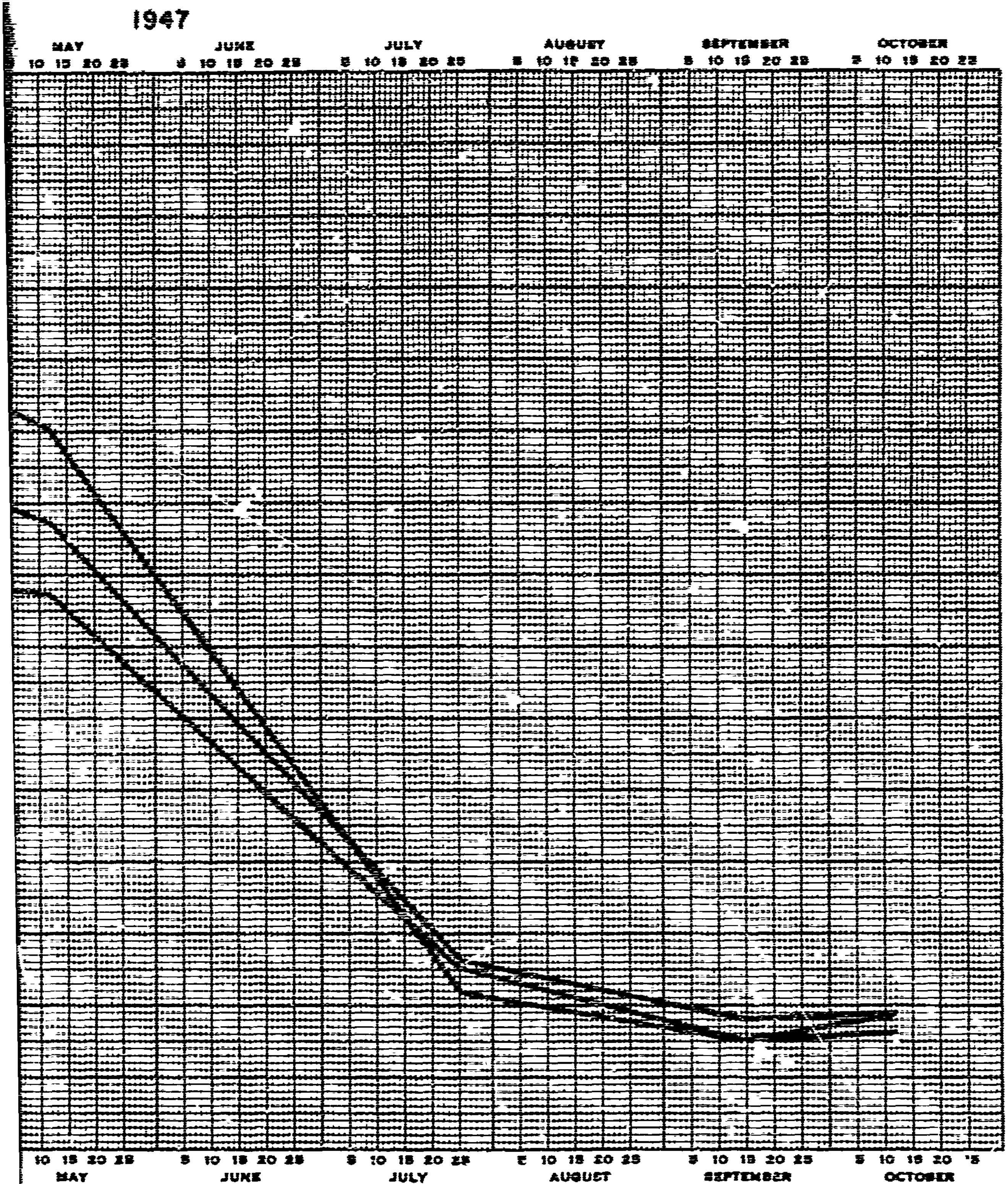
1947



GENERAL NOTES:
BASED ON AVERAGE MOVEMENT OF THREE POINTS IN SECTIONS A, B, & C.

PERMAFROS
FIELD RESEARC
ARE
AVERAGE VEF
OF OBSERV
NOV. 194
CORPS OF ENGI

B C



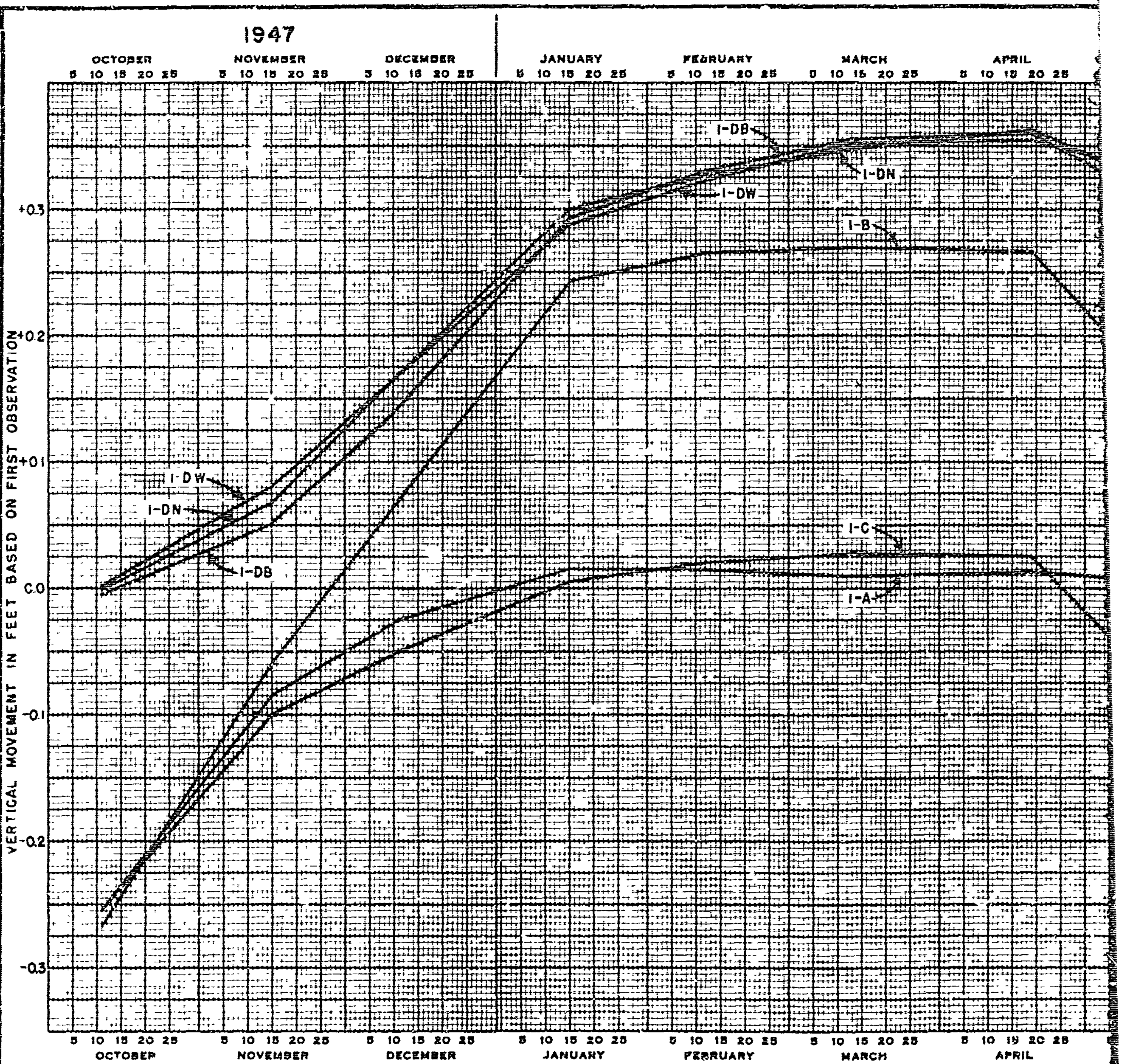
RAGE MOVEMENT OF
IN SECTIONS A, B, & C.

PERMAFROST INVESTIGATION
FIELD RESEARCH - FAIRBANKS, ALASKA
AREA NO I
AVERAGE VERTICAL MOVEMENT
OF OBSERVATION POINTS
NOV. 1946 - OCT. 1947

C

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

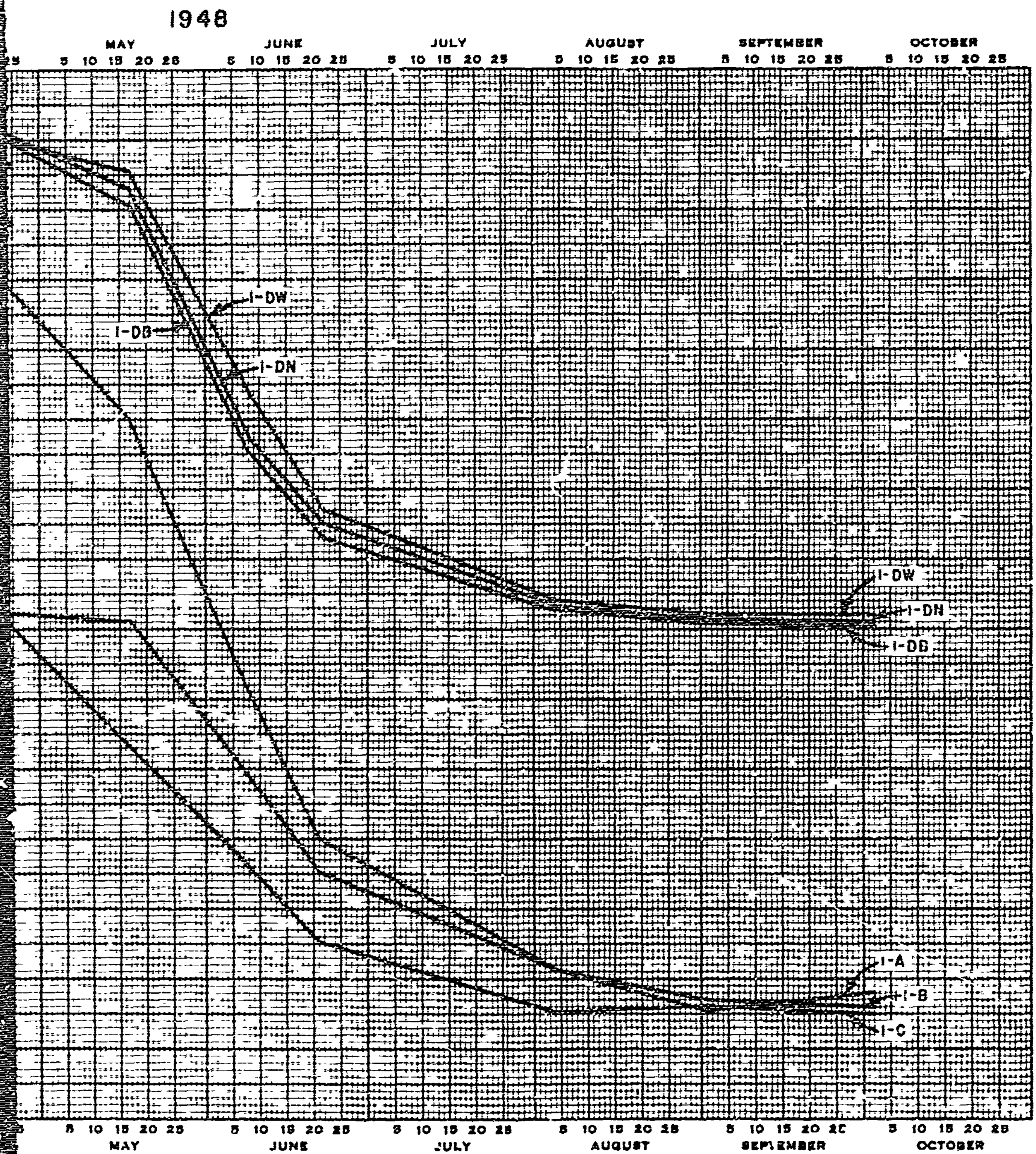
PLATE 30



DESCRIPTION OF SECTIONS
AREA NO. 1

SECTION I-A, NATURAL UNDISTURBED SECTION
" I-B, TREES AND BRUSH ONLY REMOVED
" I-C, ALL VEGETATION AND SOIL REMOVED TO 12" DEPTH
" I-DB, CONCRETE SURFACE PAINTED BLACK
" I-DN, CONCRETE SURFACE NOT PAINTED
" I-DW, CONCRETE SURFACE PAINTED WHITE

GENERAL NOTES:
BASED ON AVE
IN SECTIONS
MOVEMENT OF
SECTION D.



OTES:
ON AVERAGE MOVEMENT OF THREE POINTS
IONS A, B, & C AND AVERAGE
NT OF 4 CORNER POINTS IN
D, 1947-48 AREA NO. I

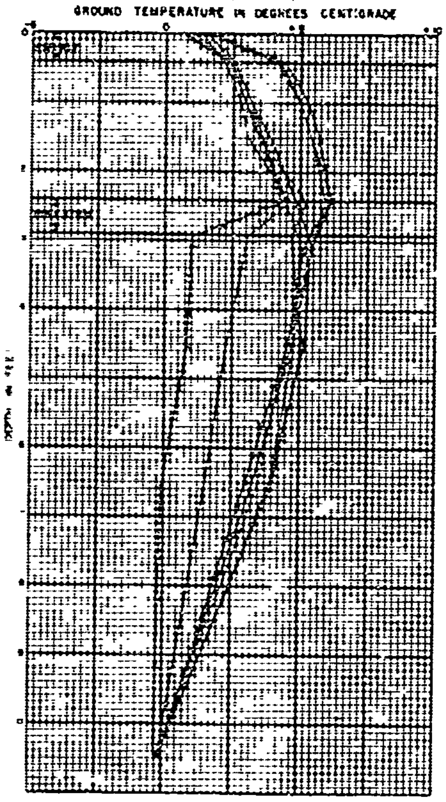
PERMAFROST INVESTIGATION

FIELD RESEARCH-FAIRBANKS, ALASKA
AREA NO. I
AVERAGE VERTICAL MOVEMENT
OF OBSERVATION POINTS
OCT. 1947-OCT. 1948
CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 31

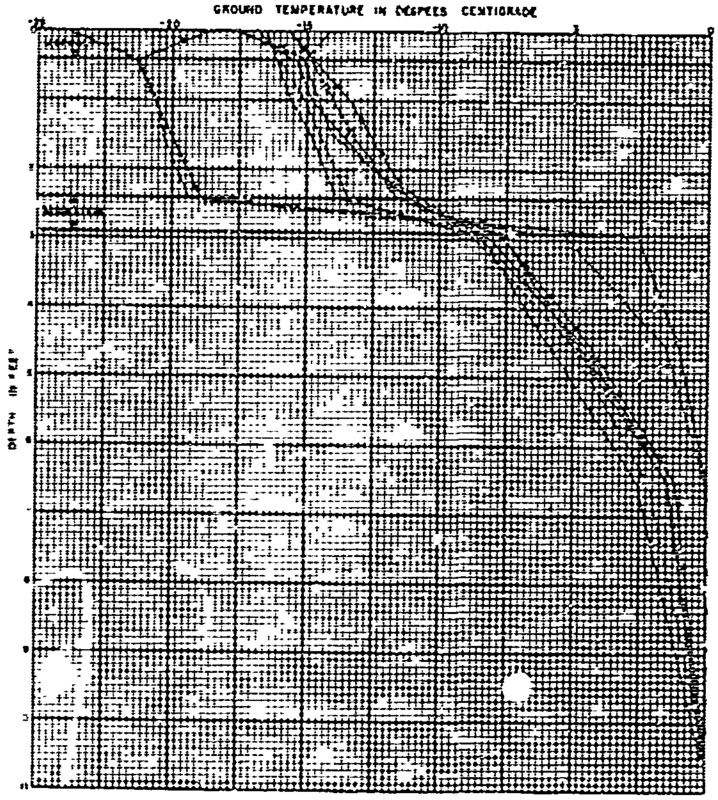
1 OCTOBER 1947

GROUND TEMPERATURE IN DEGREES CENTIGRADE



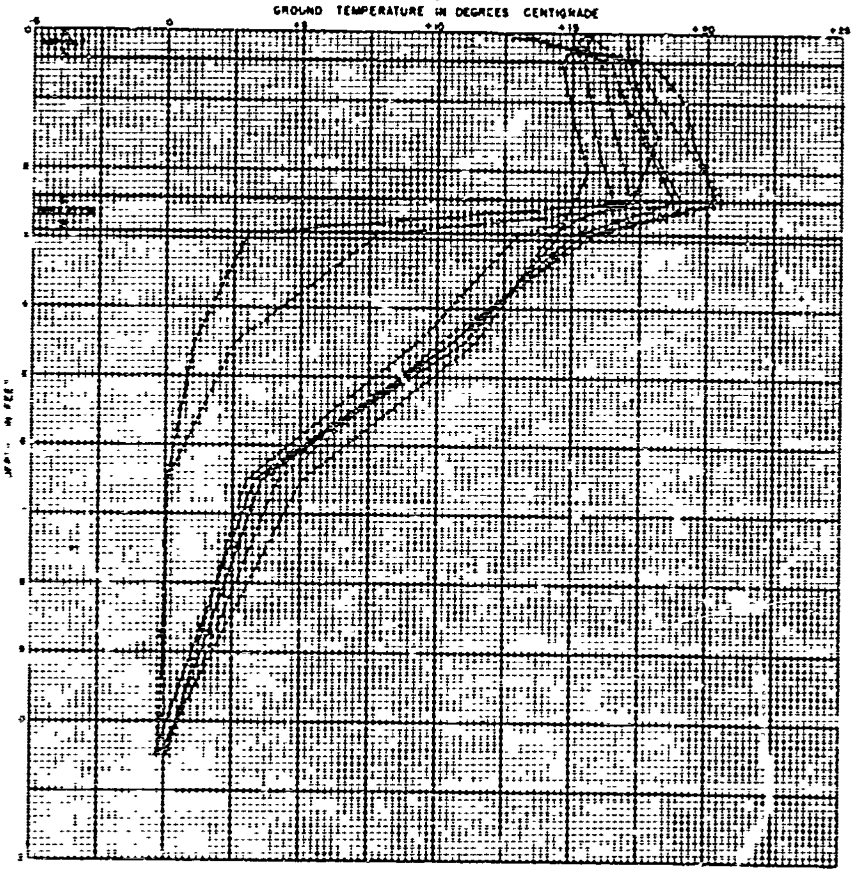
3 MARCH 1948

GROUND TEMPERATURE IN DEGREES CENTIGRADE



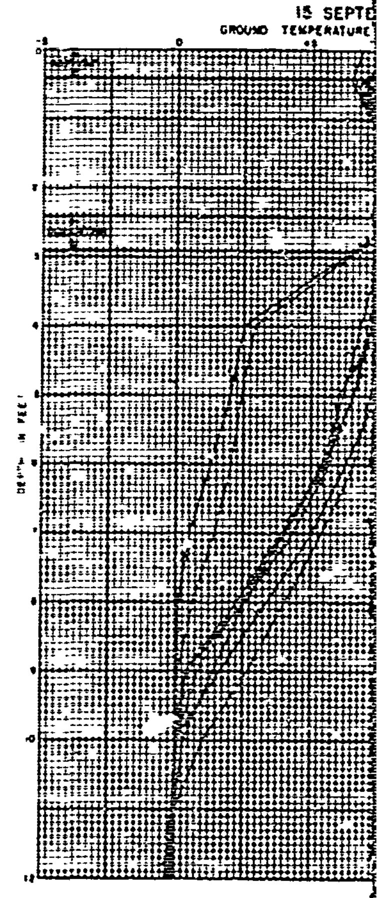
21 JULY 1948

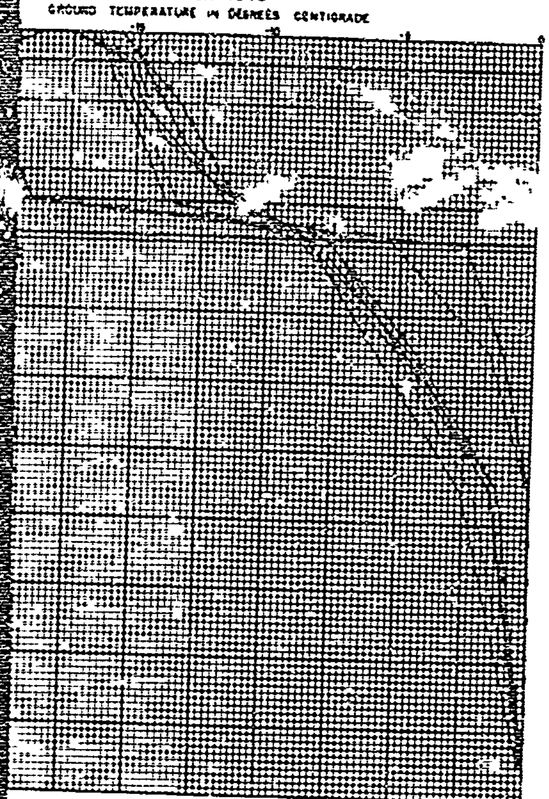
GROUND TEMPERATURE IN DEGREES CENTIGRADE

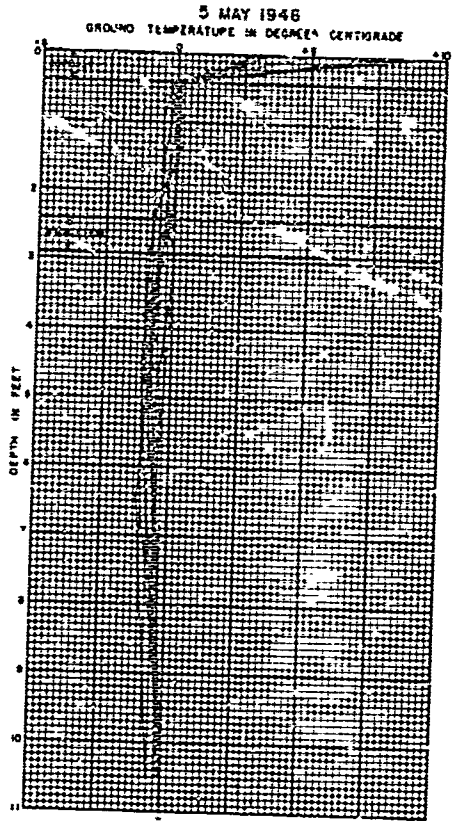


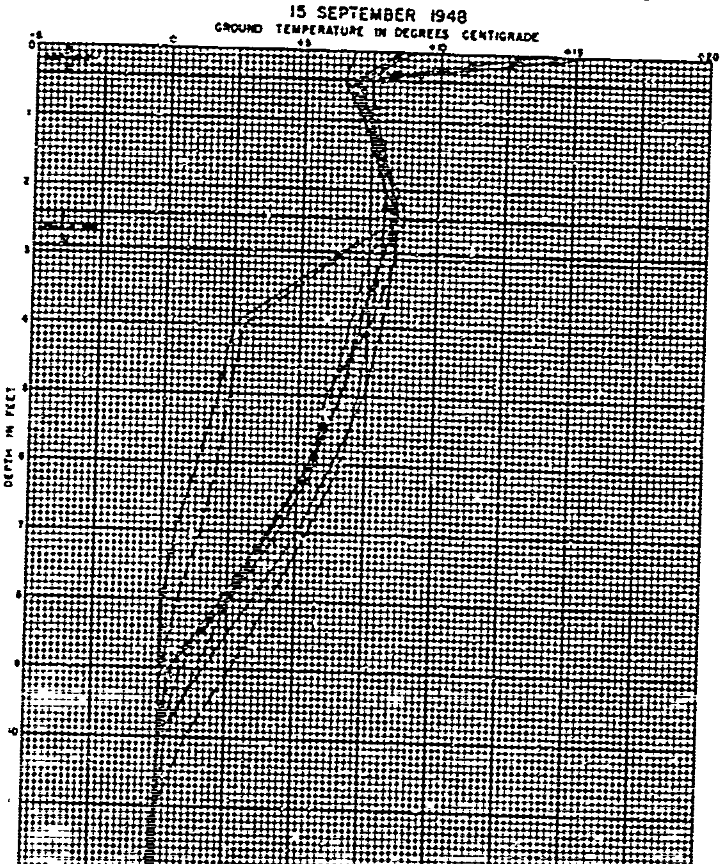
15 SEPTE

GROUND TEMPERATURE







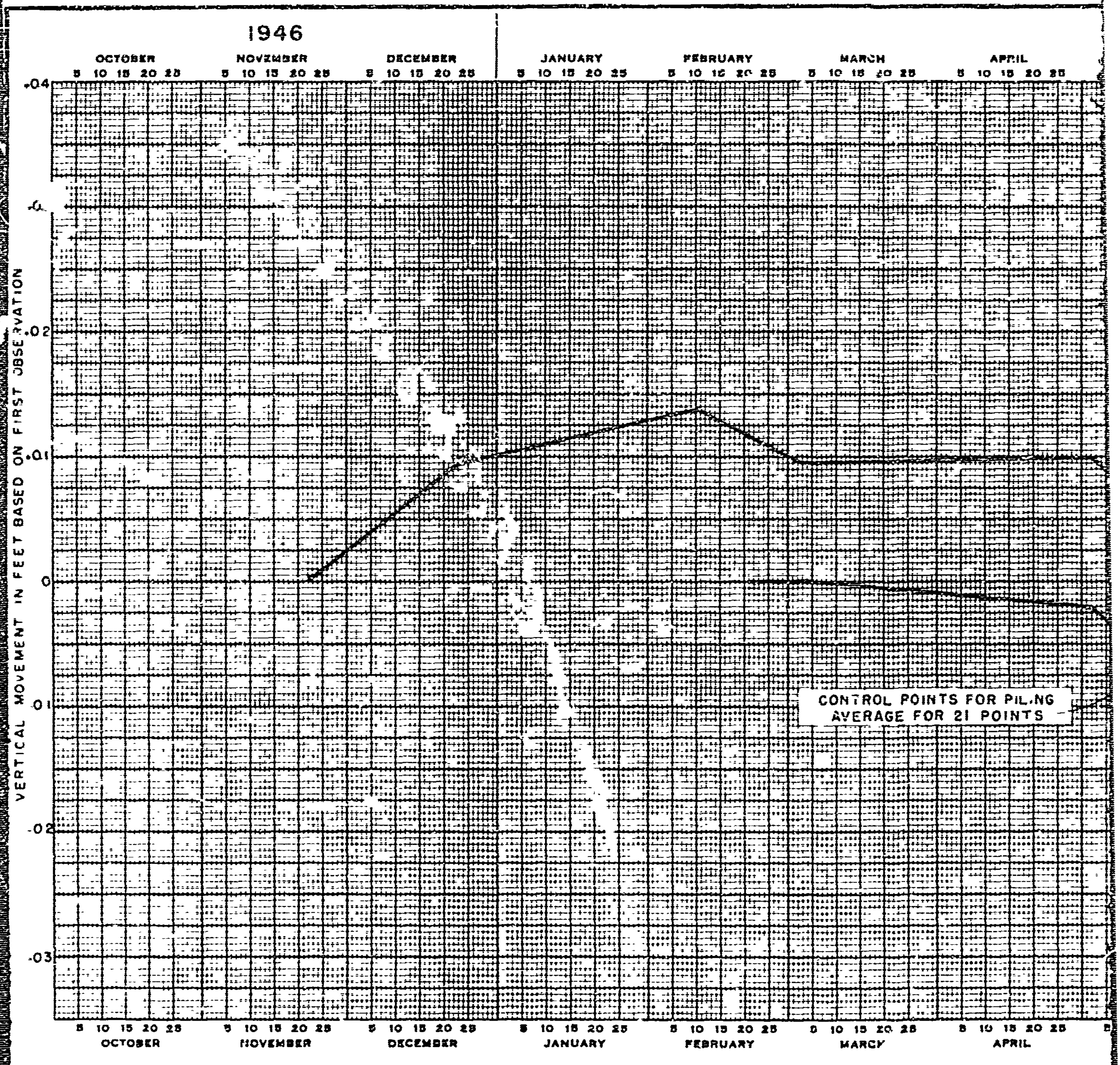


LEGEND

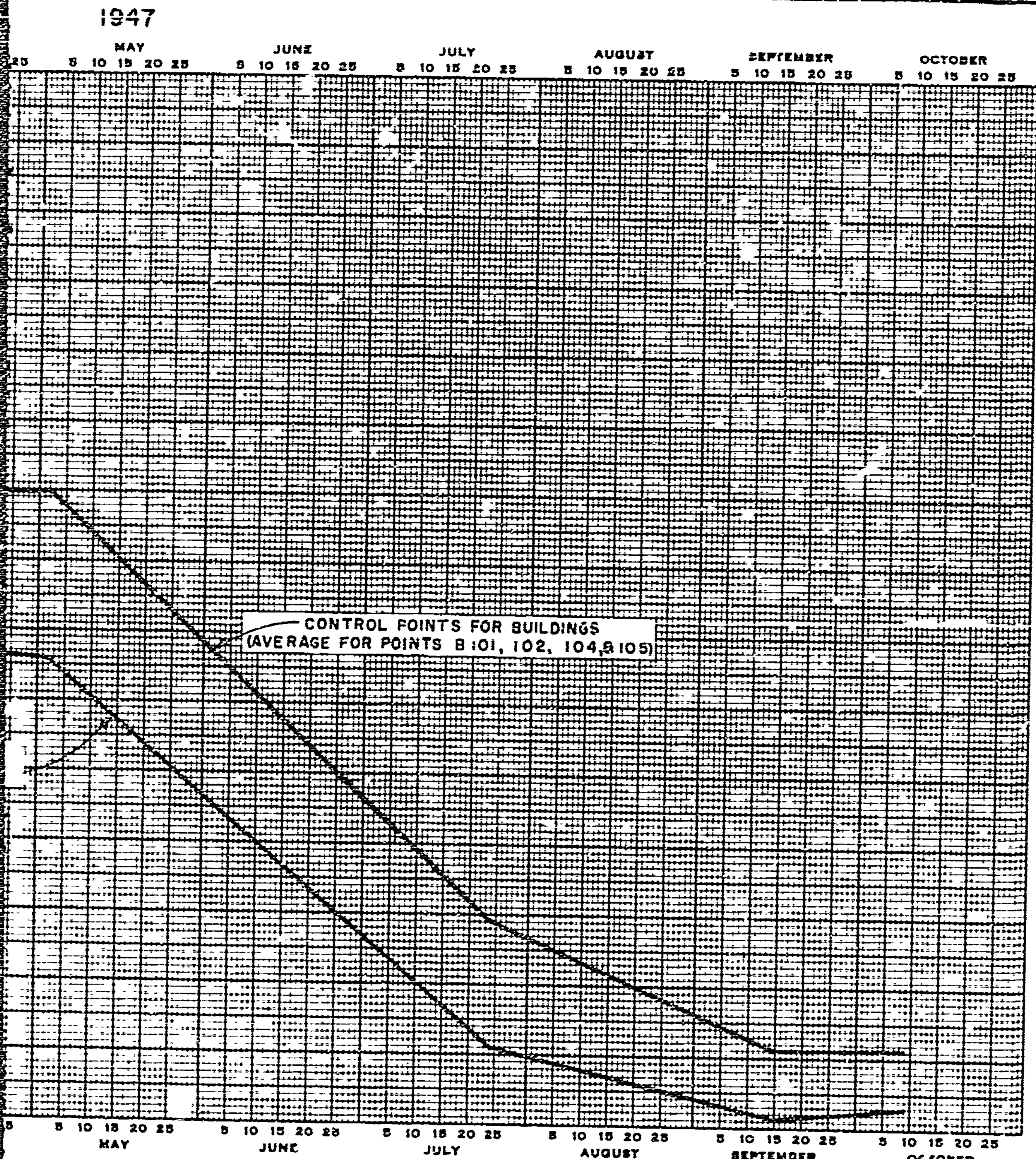
SYMBOL	HOLE NO.	MATERIAL	THICKNESS
	RN-4	NO INSULATION	
	RN-6	P.C. FOAMGLAS - SUMMER CONSTR	6"
	RN-7	CELL CONCRETE - (MEDIUM DENSITY)	6"
	RN 8	CELL CONCRETE (LOW DENSITY)	6"
	RN-11	P.C. FOAMGLAS - WINTER CONSTR	6"
	RN 19	COMPACTED SPRUCE BRANCHES	6"
	RN 20	COMPACTED MOSS	6"
	RN 21	ZONOLITE CONCRETE	6"

PERMAFROST INVESTIGATION
FIELD RESEARCH
FAIRBANKS, ALASKA
AREA NO 2
EFFECT OF INSULATION ON
GROUND TEMPERATURES
1 OCTOBER 1947 TO 15 SEPTEMBER 1948
SCALE AS SHOWN
CORPS OF ENGINEERS ST PAUL, MINN MAY 1950

PLATE 32

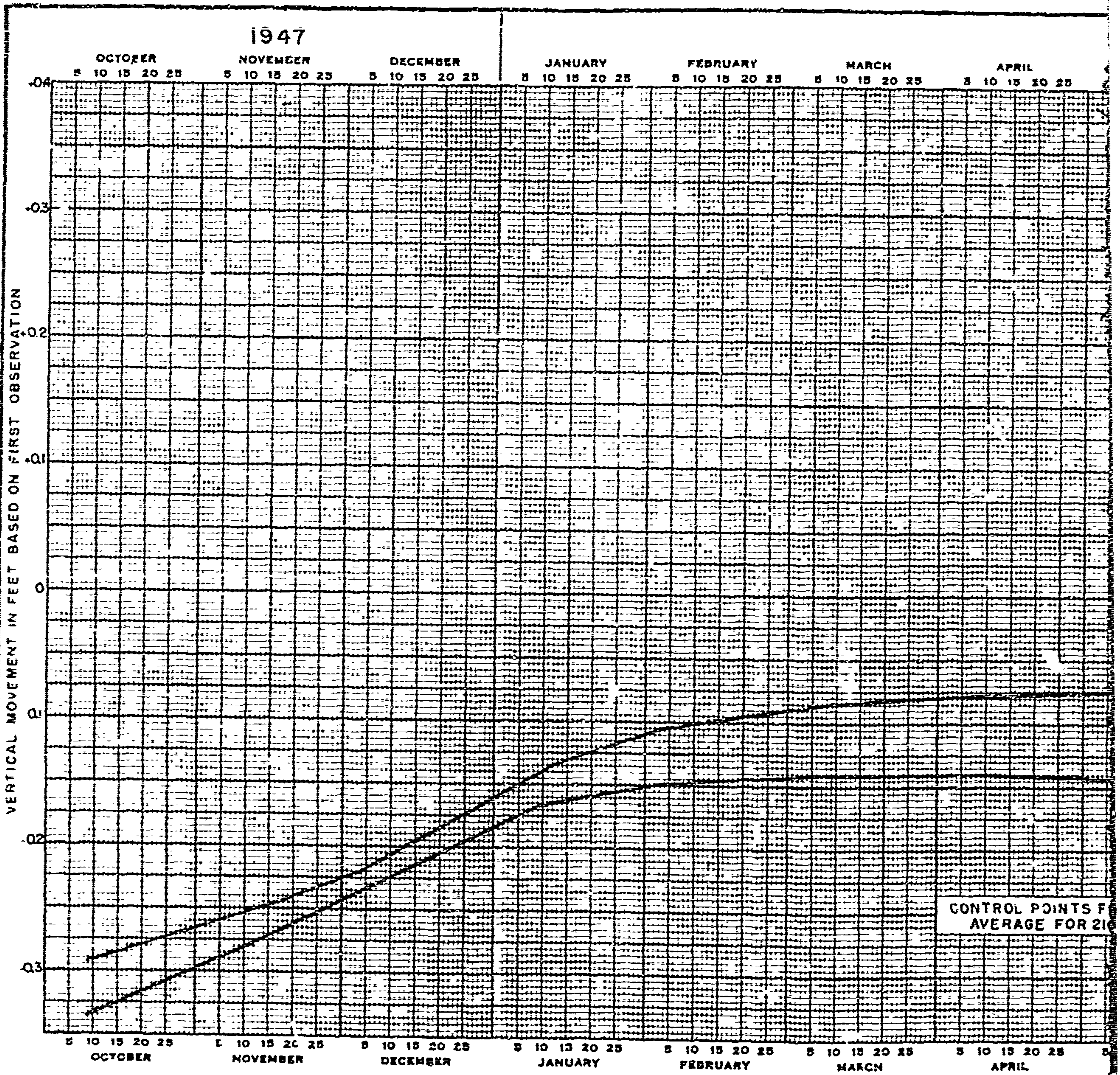


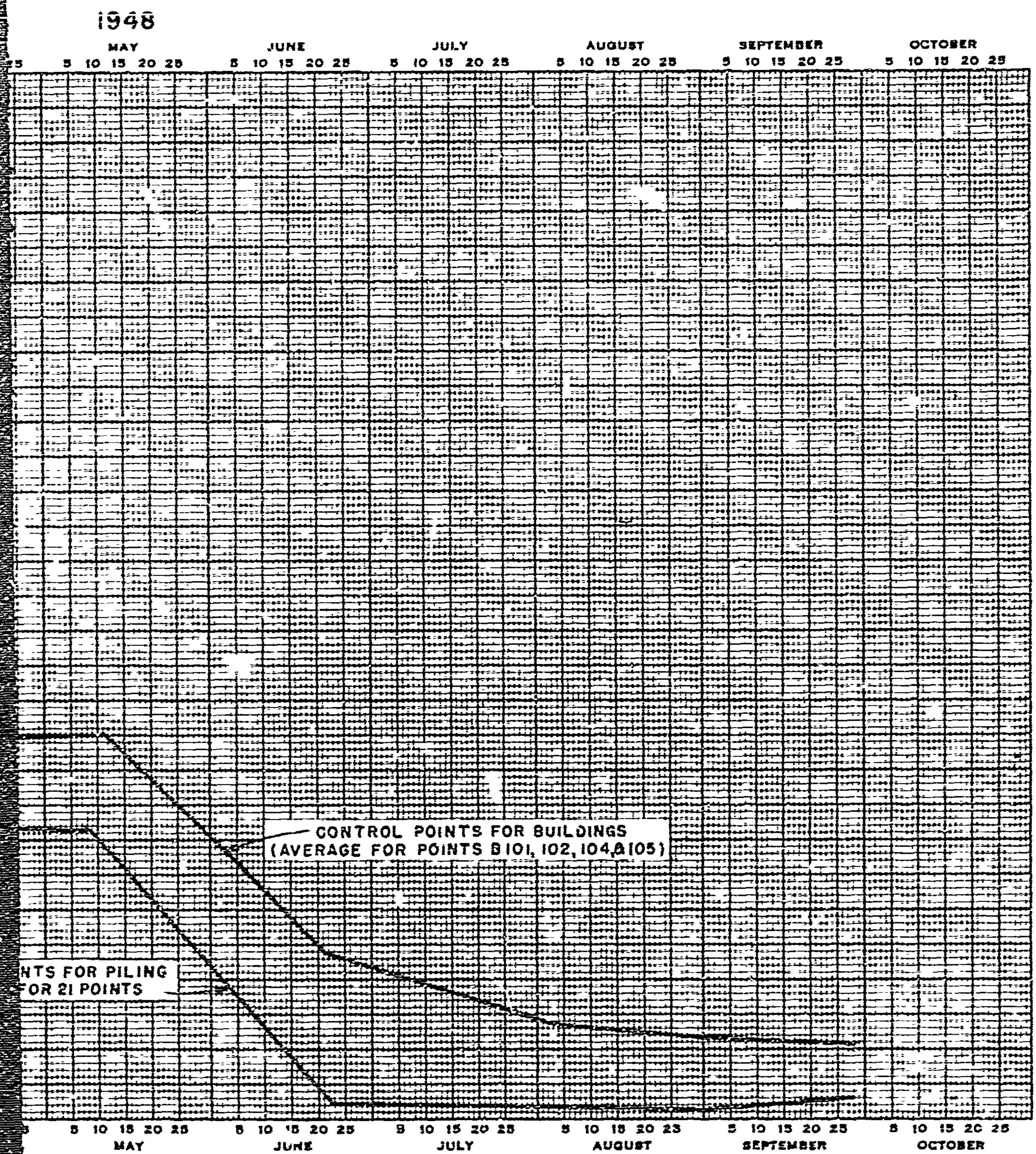
1946
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
5 10 15 20 25
.04
.02
.01
0
-.01
-.02
-.03
VERTICAL MOVEMENT IN FEET BASED ON FIRST OBSERVATION
CONTROL POINTS FOR PILING
AVERAGE FOR 21 POINTS



PERMAFROST INVESTIGATION
FIELD RESEARCH-FAIRBANKS, ALASKA
AREA NO. 3
DIFFERENTIAL MOVEMENT OF CONTROL POINTS
NOV. 1946-OCT. 1947
CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 33


1947
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
5 10 15 20 25
+0.4
+0.3
+0.2
+0.1
0
-0.1
-0.2
-0.3
VERTICAL MOVEMENT IN FEET BASED ON FIRST OBSERVATION
CONTROL POINTS F
AVERAGE FOR 21



PERMAFROST INVESTIGATION

FIELD RESEARCH—FAIRBANKS, ALASKA

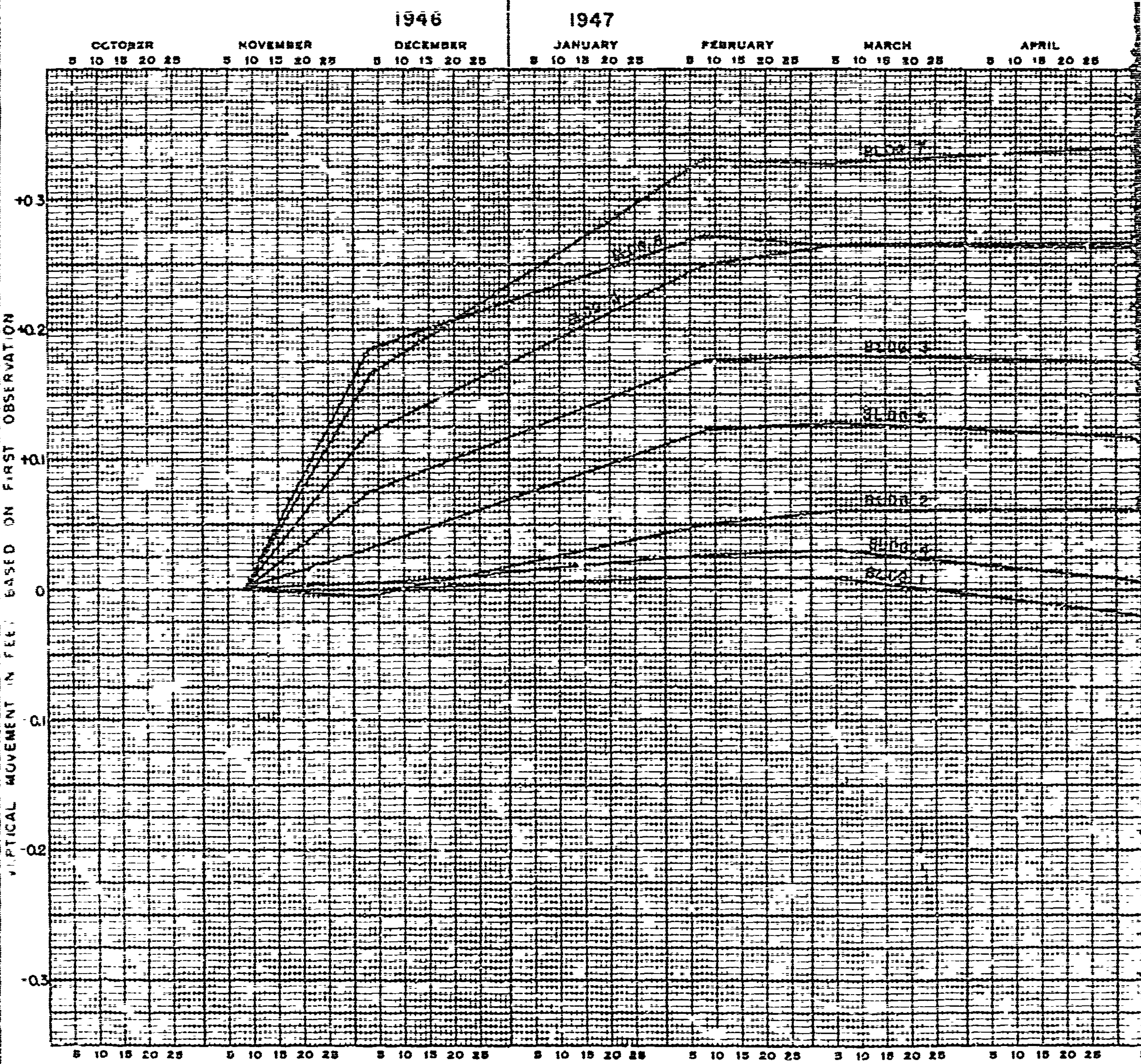
AREA NO. 3

DIFFERENTIAL MOVEMENT OF CONTROL POINTS

OCT. 1947—OCT. 1948

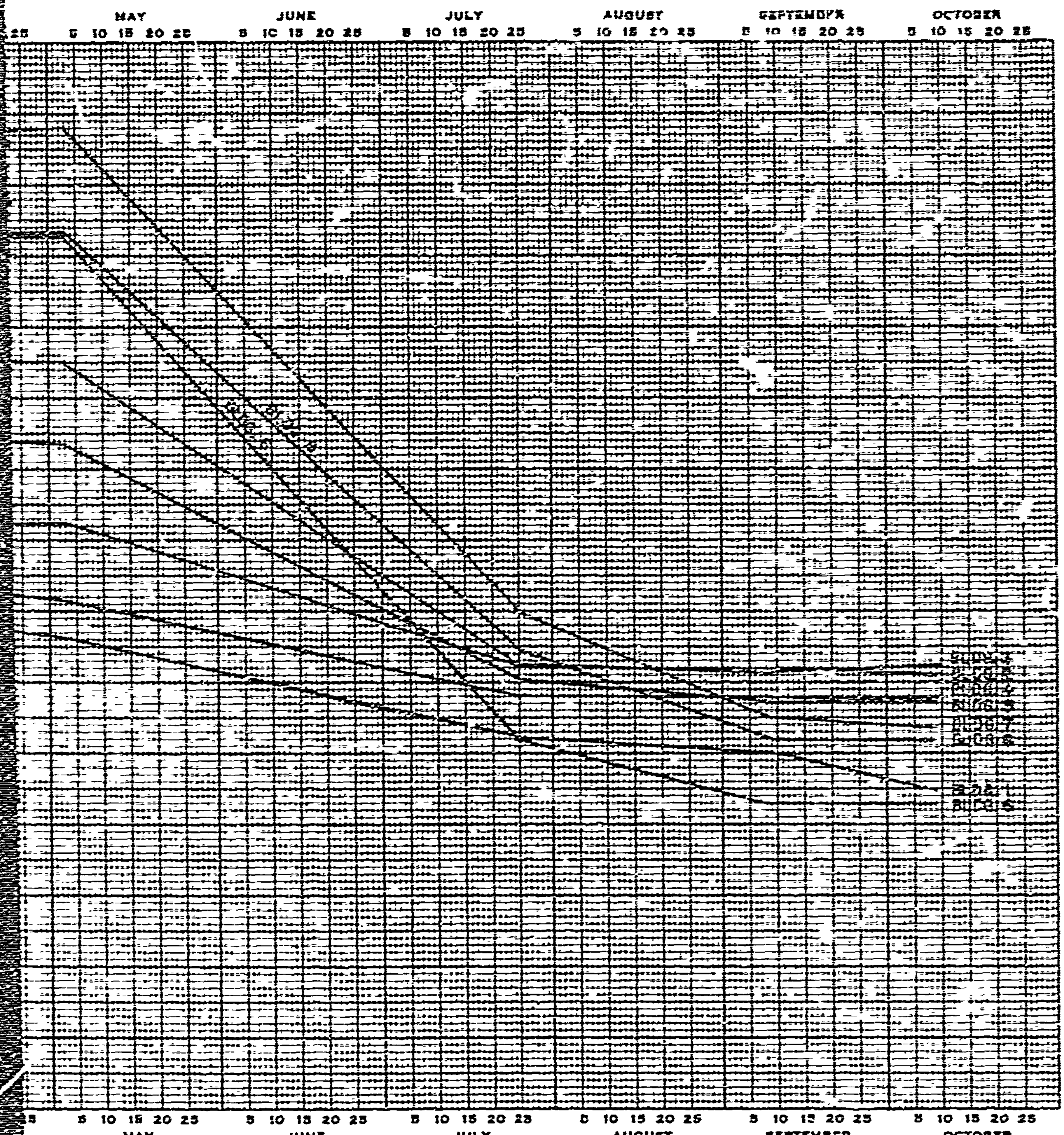
CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 34



DESCRIPTION OF BUILDINGS, AREA NO 3

BUILDING NO	FLOOR	FOUNDATION MATERIAL	FOUNDATION THICKNESS	INSULATION IN FILL
1	CONCRETE	SAND & GRAVEL	4 FT	NONE
2	INSUL. WOOD	"	4 "	"
3	"	"	2 "	"
4	"	"	6 "	"
5	"	"	4 "	CELL CONCRETE
6	"	POSTS & PADS	NO SKIRTING	2' AIR SPACE UNDER FLOOR
7	"	"	WITH SKIRTING	" " " " "
8	"	MUD SILLS	ON NATURAL GROUND	



PERMAFROST INVESTIGAT ON

FIELD RESEARCH-FAIRBANKS, AL SKA

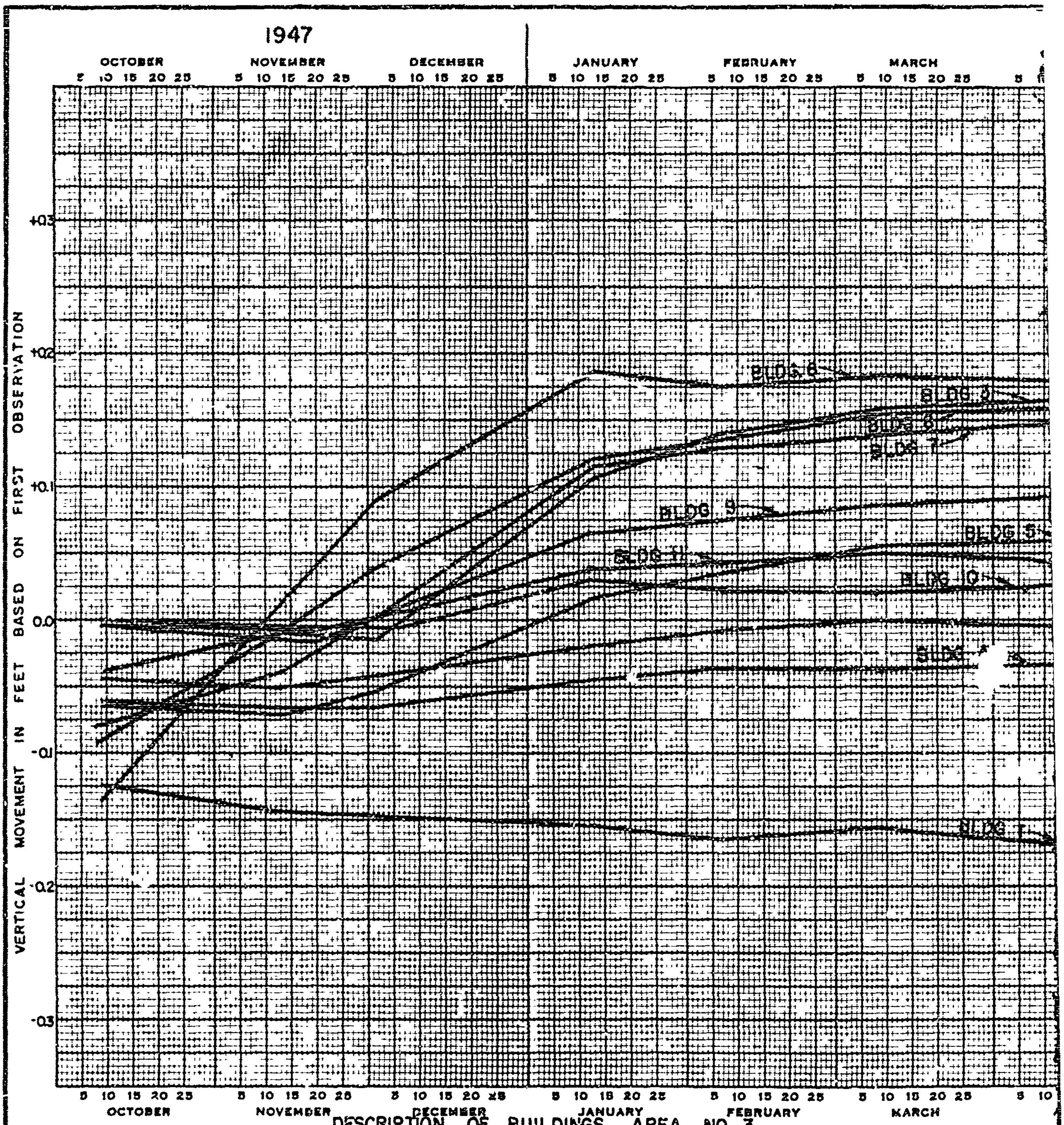
AREA NO. 3

AVERAGE VERTICAL MOVEMENT OF LDINGS

OCT. 1946-OCT. 1947

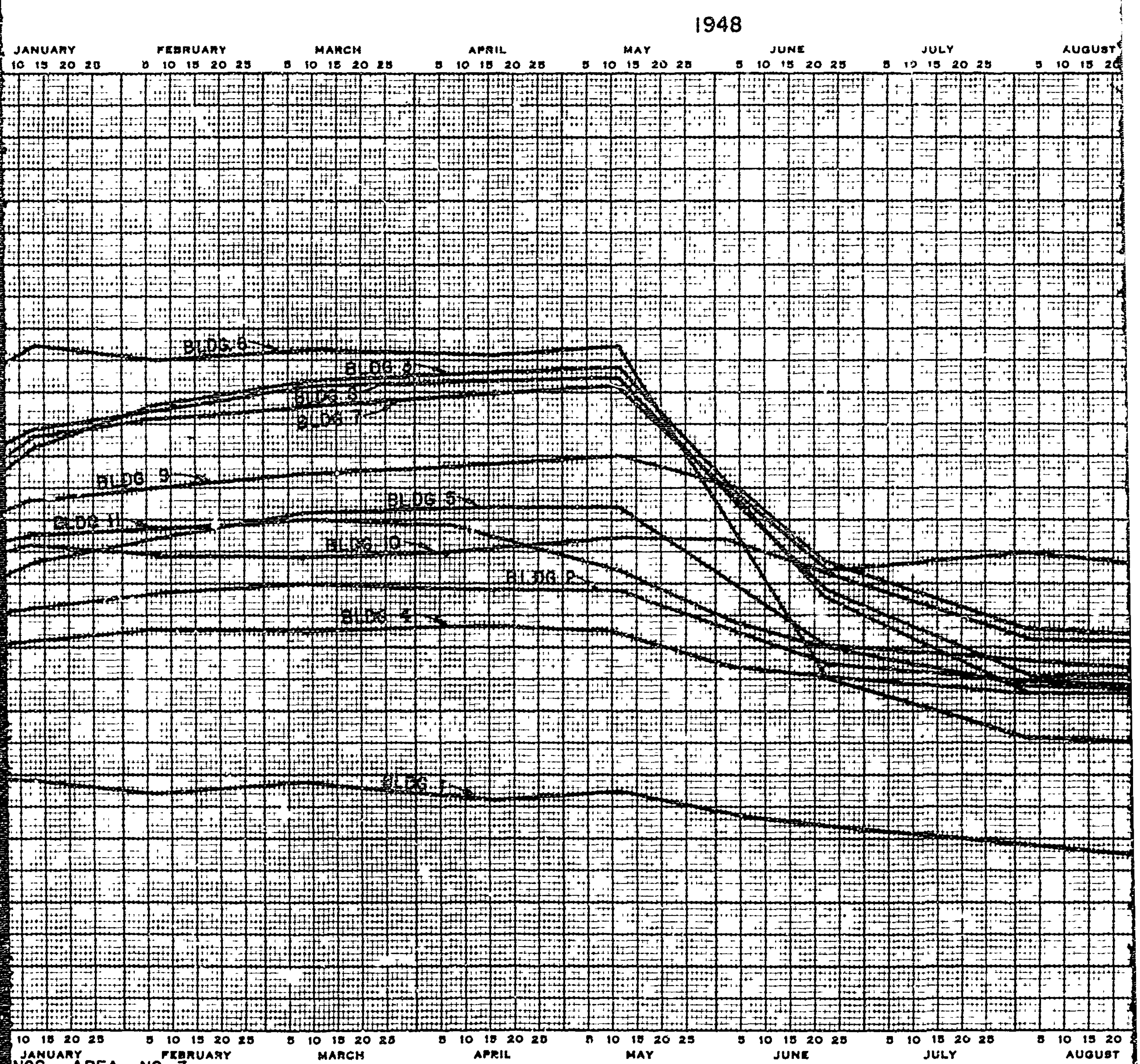
CORPS OF ENGINEERS, ST. PAUL, MINN. 1950

PLATE 35



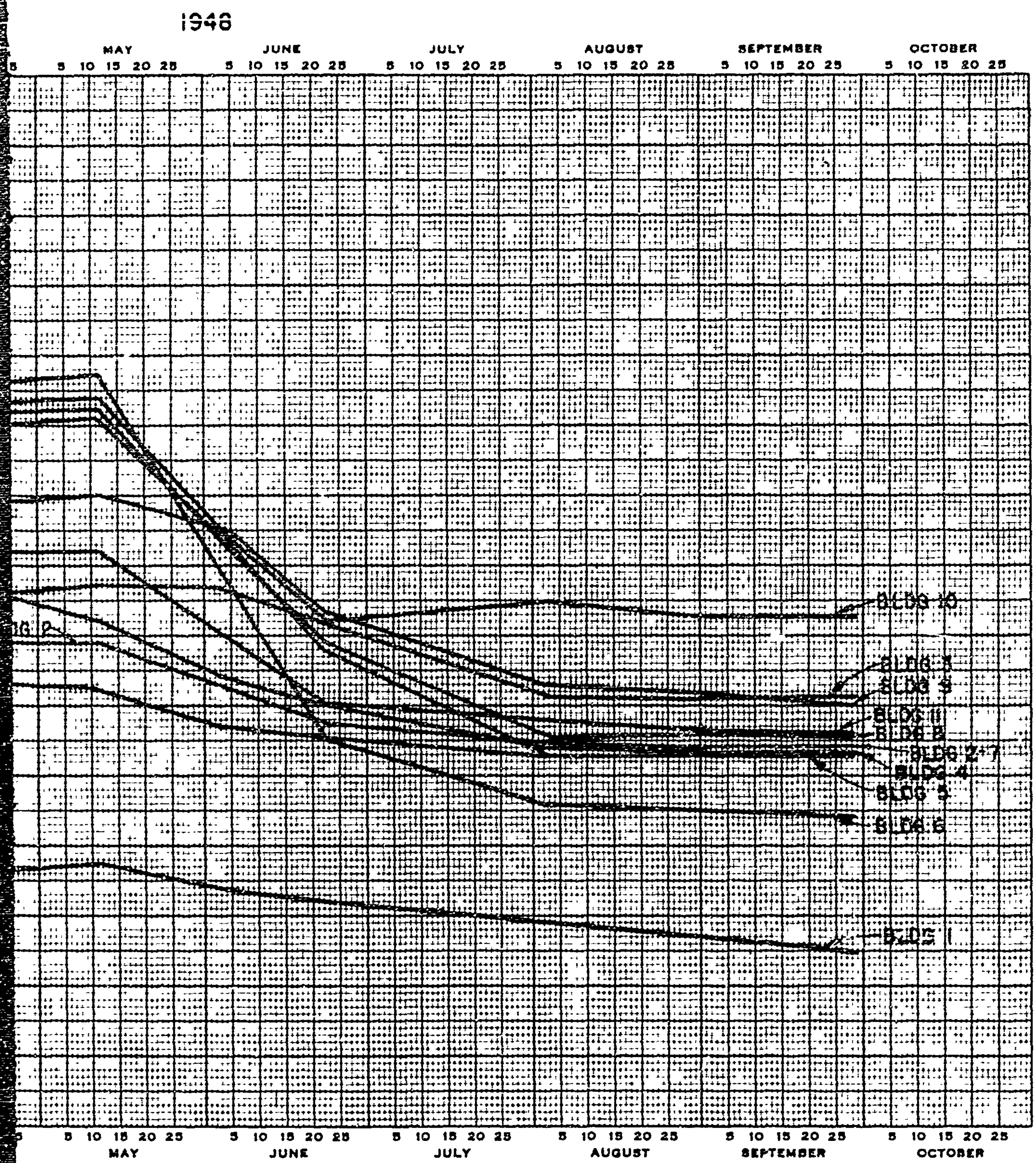
DESCRIPTION OF BUILDINGS, AREA NO. 3

BUILDING NO.	FLOOR	FOUNDATION MATERIAL	FOUNDATION THICKNESS	INSULATION IN FILL
1	CONCRETE	SAND AND GRAVEL FILL	4'	NONE
2	INSULATED WOOD	SAND AND GRAVEL FILL	4'	NONE
3	INSULATED WOOD	SAND AND GRAVEL FILL	2'	NONE
4	WOOD	SAND AND GRAVEL FILL	[illegible]'	NONE
5	INSULATED WOOD	SAND AND GRAVEL FILL	4'	CELL CONCRETE
6	INSULATED WOOD	POSTS AND PADS ON EARTH	NO SKIRTING	2" AIR SPACE UNDER FLOOR
7	INSULATED WOOD	POSTS AND PADS ON EARTH	WITH SKIRTING	2" AIR SPACE UNDER FLOOR
8	INSULATED WOOD	MUD SILLS ON EARTH		2" AIR SPACE UNDER FLOOR
9	INSULATED WOOD OVER CONCRETE	CONCRETE SLAB ON 5' S.& G. FILL	3' AIR SPACE	NONE
10	INSULATED WOOD	WOOD PILES ON EARTH	5' AIR SPACE	NONE
11	CONCRETE	TILE & CONC. SLAB ON 5' S.& G. FILL	3" AIR SPACE	NONE



NGS, AREA NO. 3

FOUNDATION	THICKNESS	INSULATION IN FILL
AVEL FILL	4'	NONE
AVEL FILL	4'	NONE
AVEL FILL	2'	NONE
AVEL FILL	6'	NONE
AVEL FILL	4'	CELL CONCRETE
ADS ON EARTH	NO SKIRTING	2"AIR SPACE UNDER FLOOR
DS ON EARTH	WITH SKIRTING	2"AIR SPACE UNDER FLOOR
ON EARTH		2"AIR SPACE UNDER FLOOR
5' S.&G. FILL	3' AIR SPACE	NONE
ON EARTH	5' AIR SPACE	NONE
ON 5'S.&G. FILL	3" AIR SPACE	NONE



PERMAFROST INVESTIGATION

FIELD RESEARCH - FAIRBANKS, ALASKA

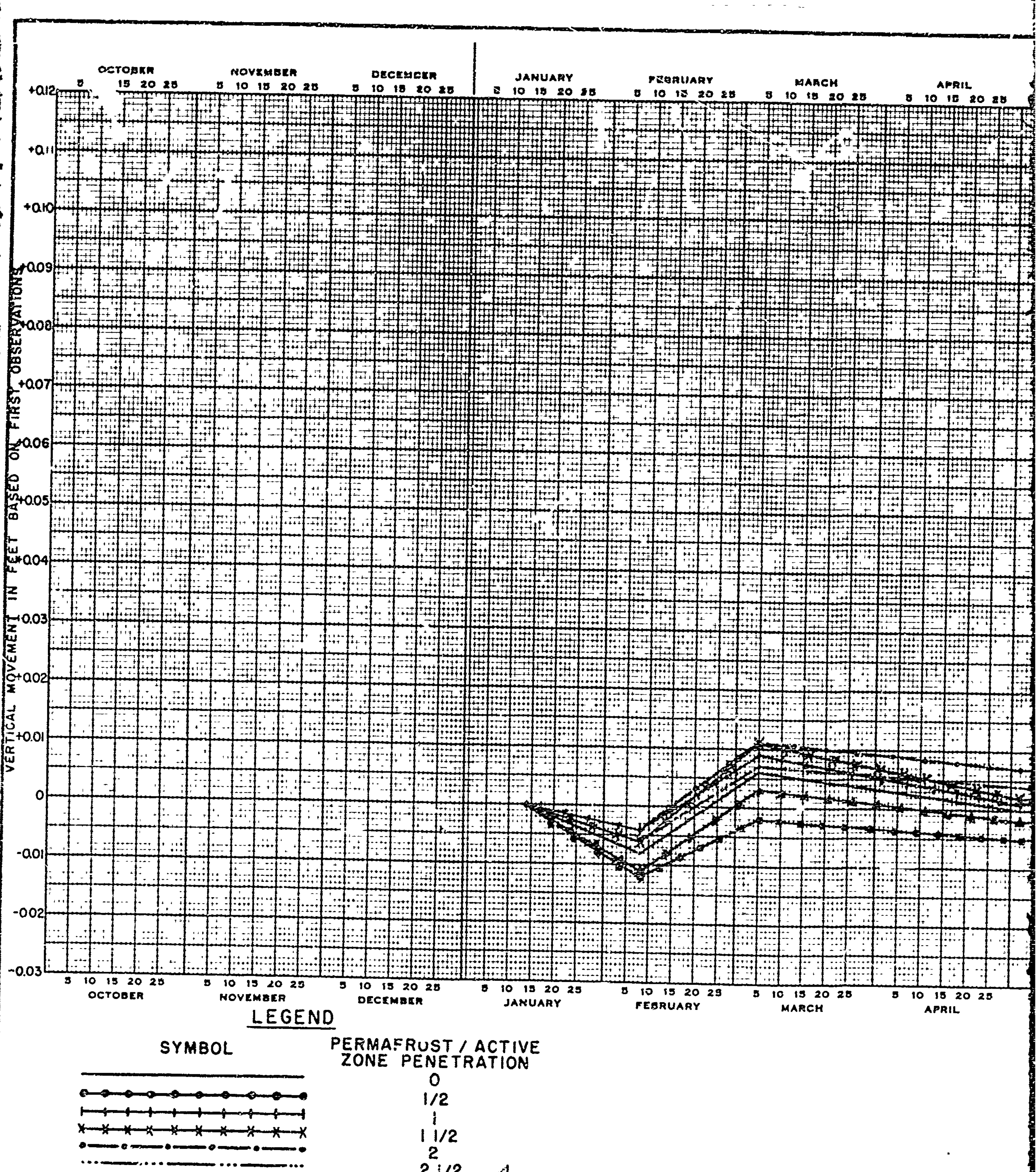
AREA NO. 3

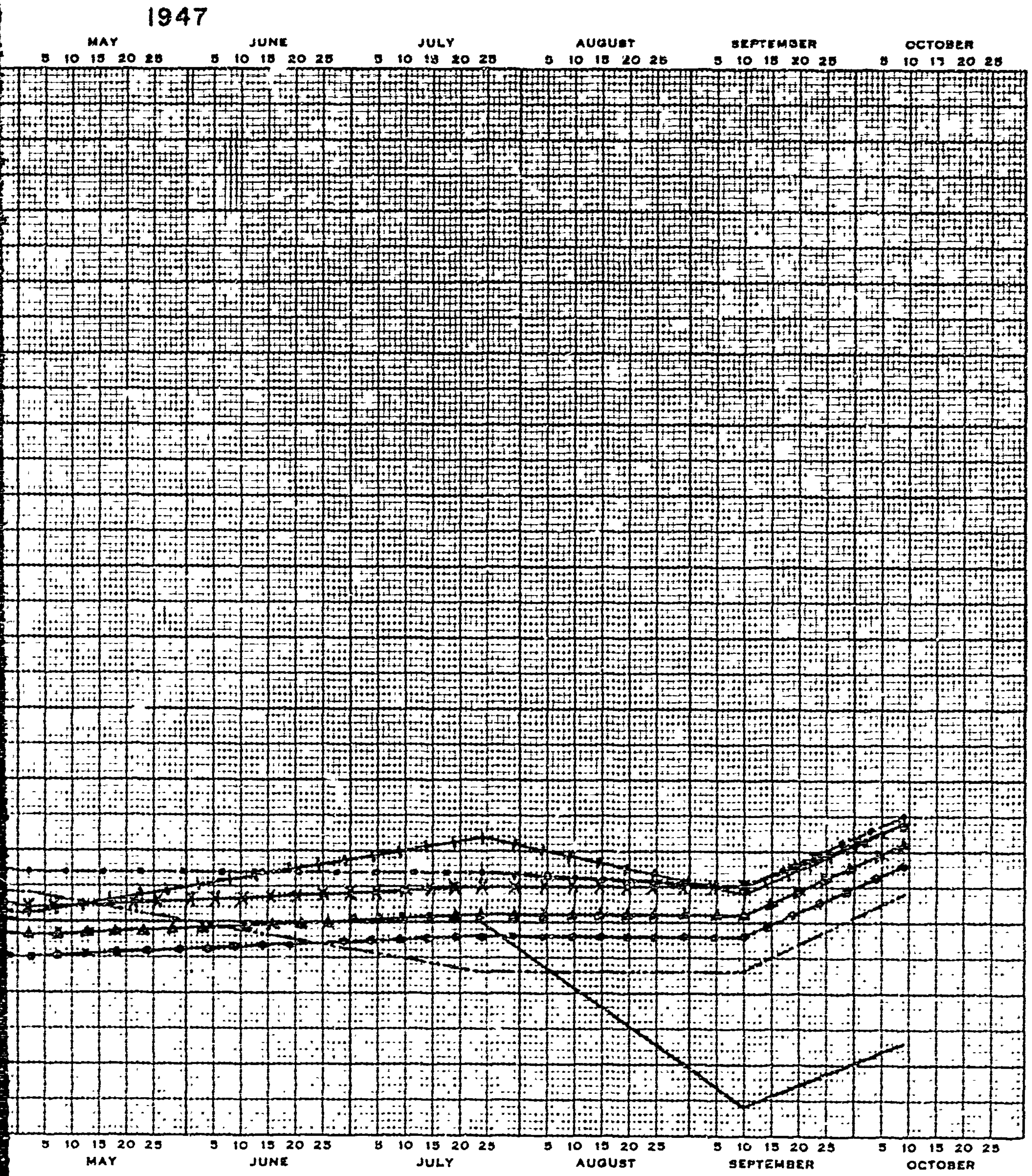
AVERAGE VERTICAL MOVEMENT OF BUILDINGS

OCT. 1947-OCT. 1948

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 36


OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
5 10 15 20 25
VERTICAL MOVEMENT IN FEET BASED ON FIRST OBSERVATIONS
+0.12
+0.11
+0.10
+0.09
+0.08
+0.07
+0.06
+0.05
+0.04
+0.03
+0.02
+0.01
0
-0.01
-0.02
-0.03
LEGEND
SYMBOL
PERMAFROST / ACTIVE ZONE PENETRATION
0
1/2
1
1 1/2
2
2 1/2
3



PERMAFROST INVESTIGATION

FIELD RESEARCH-FAIRBANKS, ALASKA

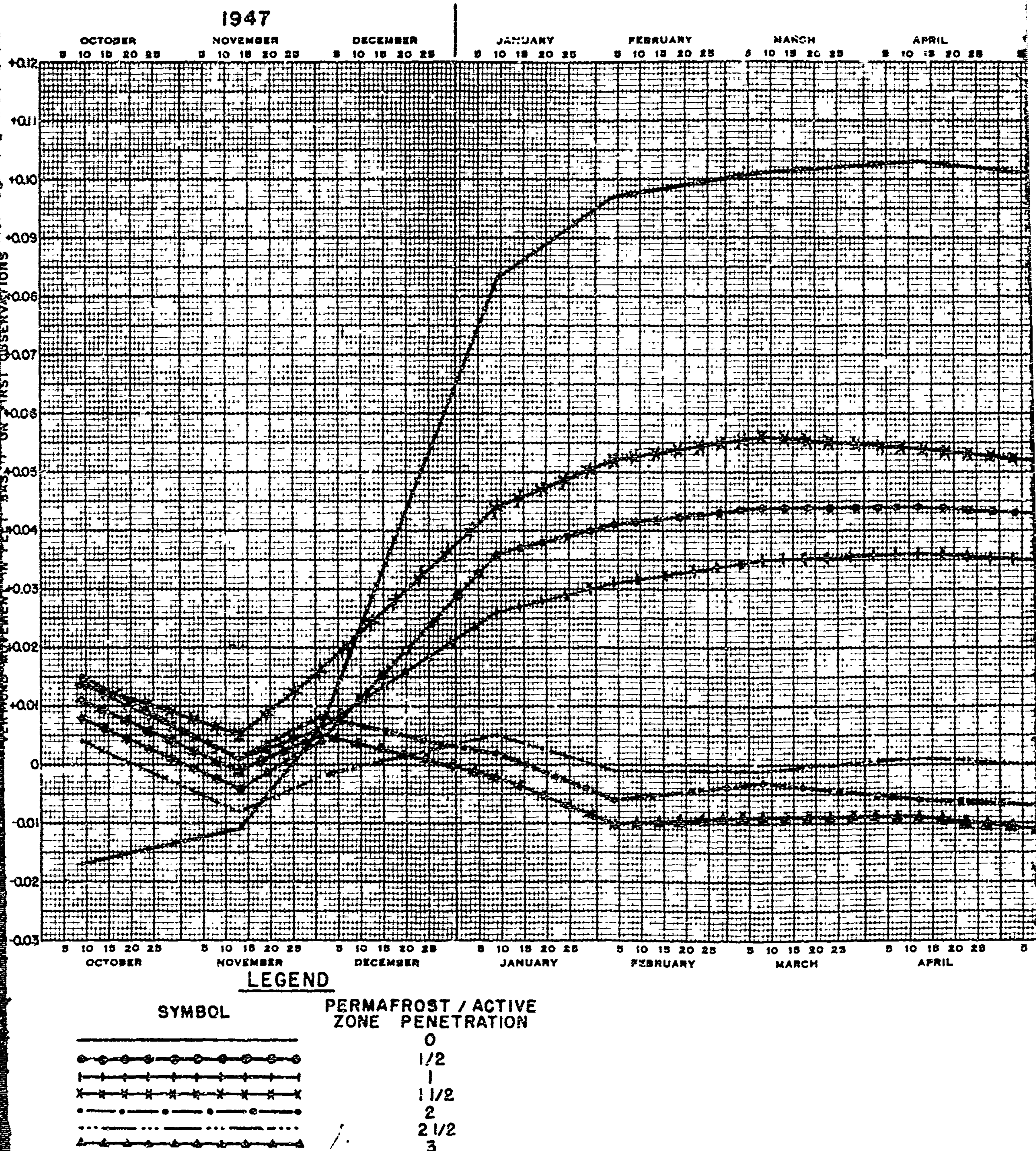
AREA NO. 3

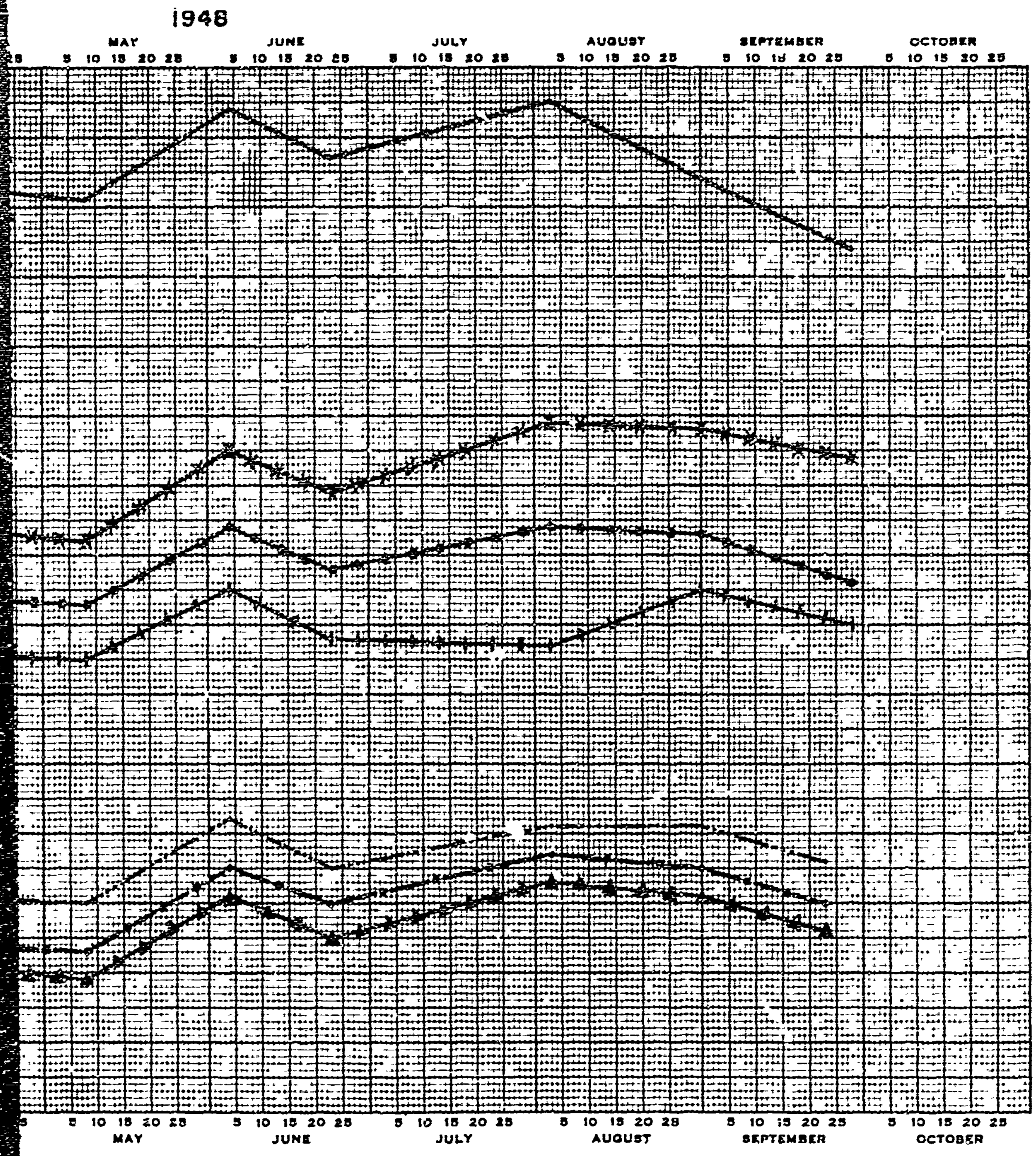
DIFFERENTIAL MOVEMENT OF PILING

JAN. 1947 - OCT. 1947

CORPS OF ENGINEERS, ST PAUL, MINN. MAY 1950

PLATE 37


1947
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
5 10 15 20 25
+0.12
+0.11
+0.10
+0.09
+0.08
+0.07
+0.06
+0.05
+0.04
+0.03
+0.02
+0.01
0
-0.01
-0.02
-0.03
LEGEND
SYMBOL
PERMAFROST / ACTIVE ZONE PENETRATION
0
1/2
1
1 1/2
2
2 1/2
3



PERMAFROST INVESTIGATION

FIELD RESEARCH - FAIRBANKS, ALASKA

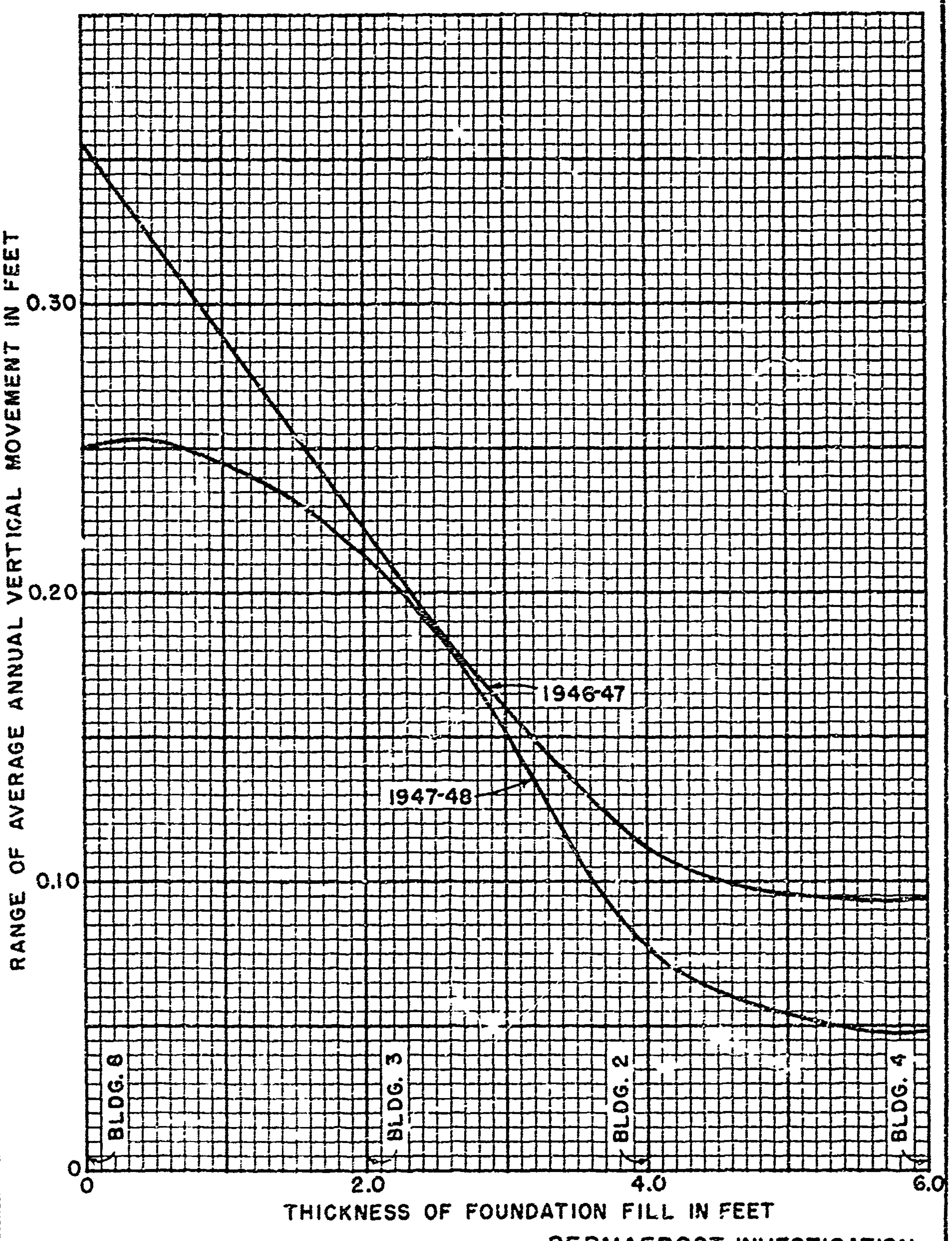
AREA NO. 3

DIFFERENTIAL MOVEMENT OF PILING

OCT. 1947 - OCT. 1948

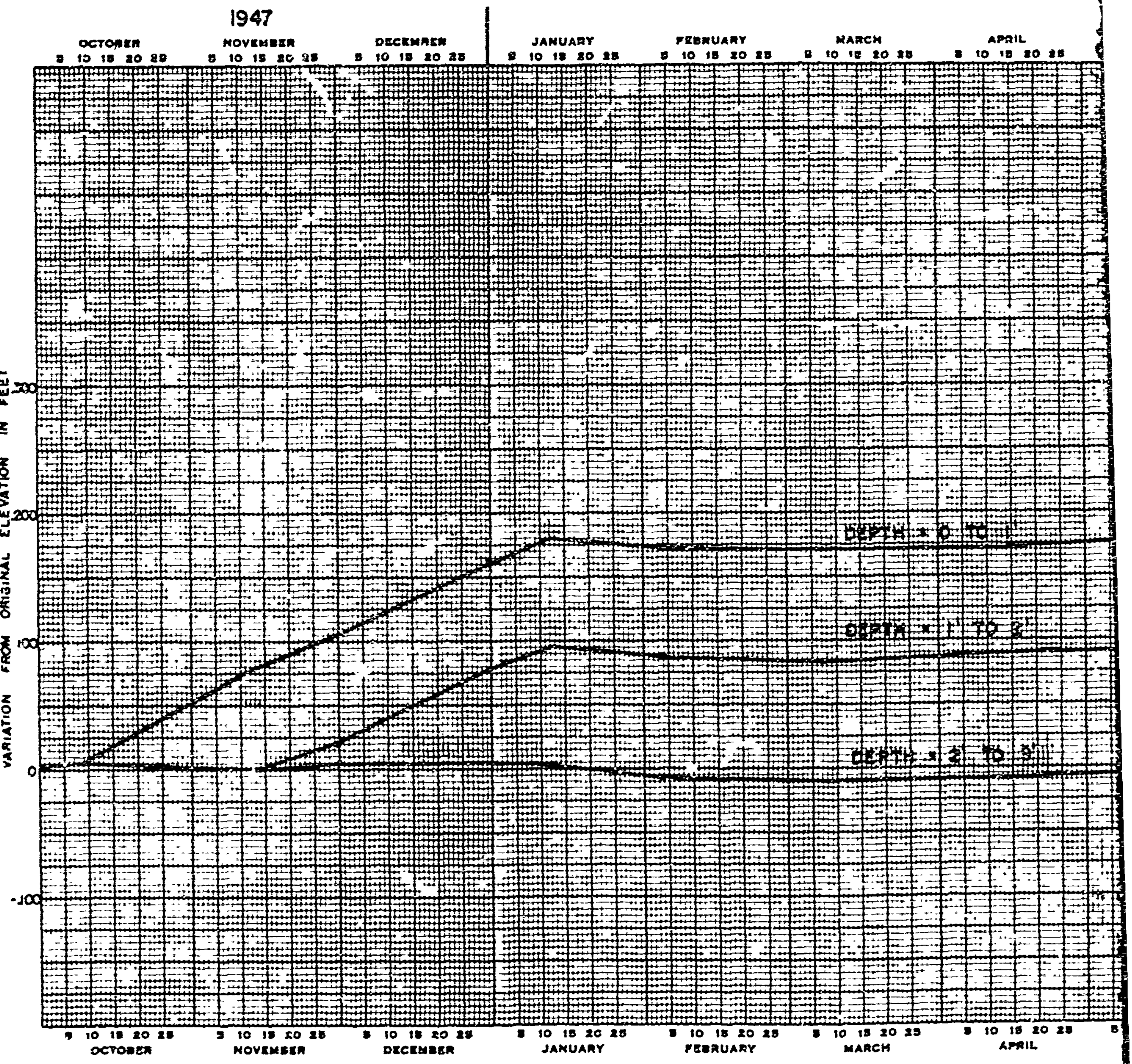
CORPS OF ENGINEERS, ST PAUL, MINN. MAY 1950

PLATE 38

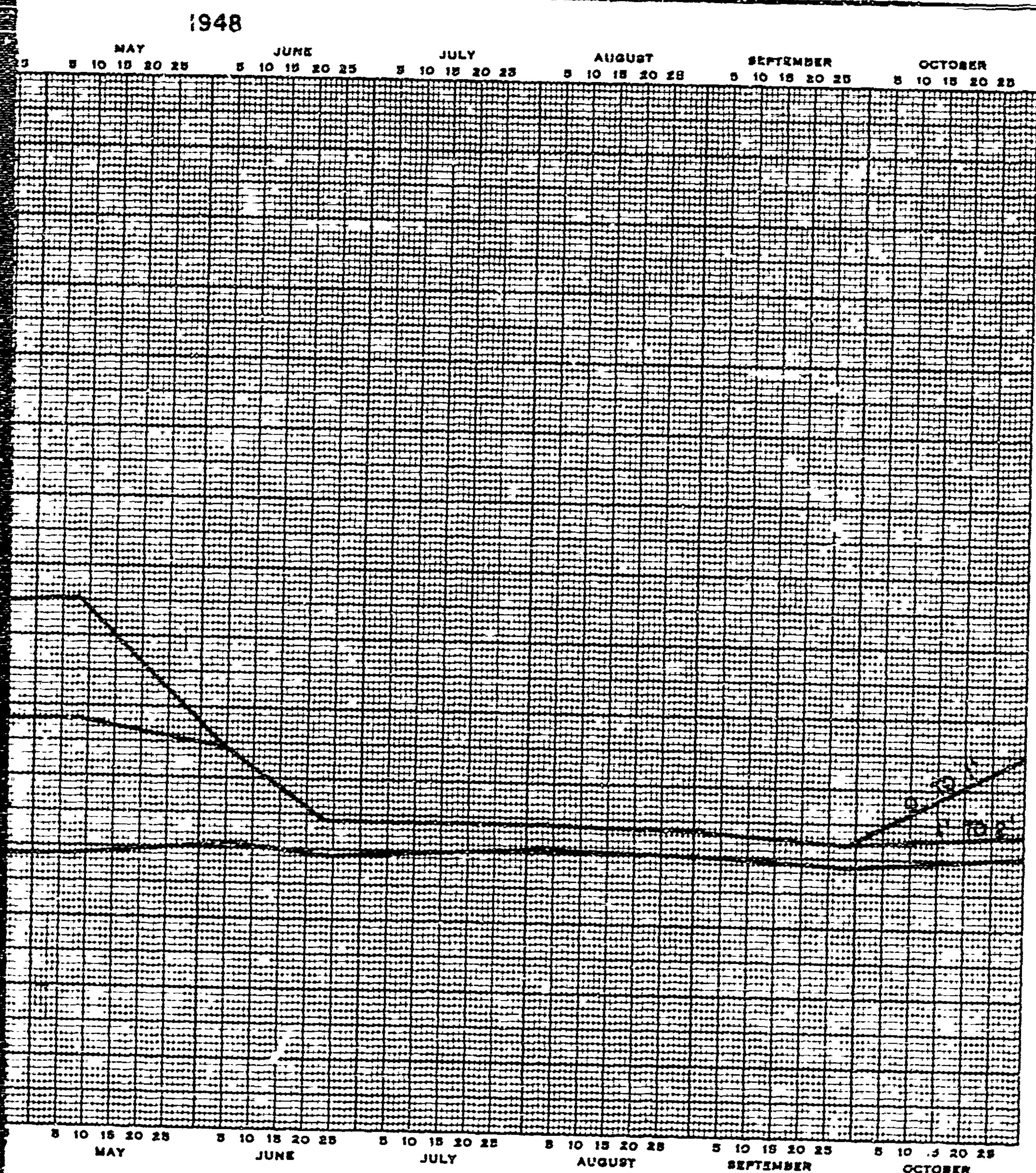


PERMAFROST INVESTIGATION
FIELD RESEARCH-FAIRBANKS, ALASKA
AREA NO. 3
RELATION OF FILL THICKNESS TO
VERTICAL MOVEMENT OF BUILDING
CORPS OF ENGINEERS ST PAUL, MINN. MAY 1950

PLATE 39



1947
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
5 10 15 20 25
VARIATION FROM ORIGINAL ELEVATION IN FEET
300
200
100
0
-100
DEPTH = 0 TO 1'
DEPTH = 1' TO 2'
DEPTH = 2' TO 3'

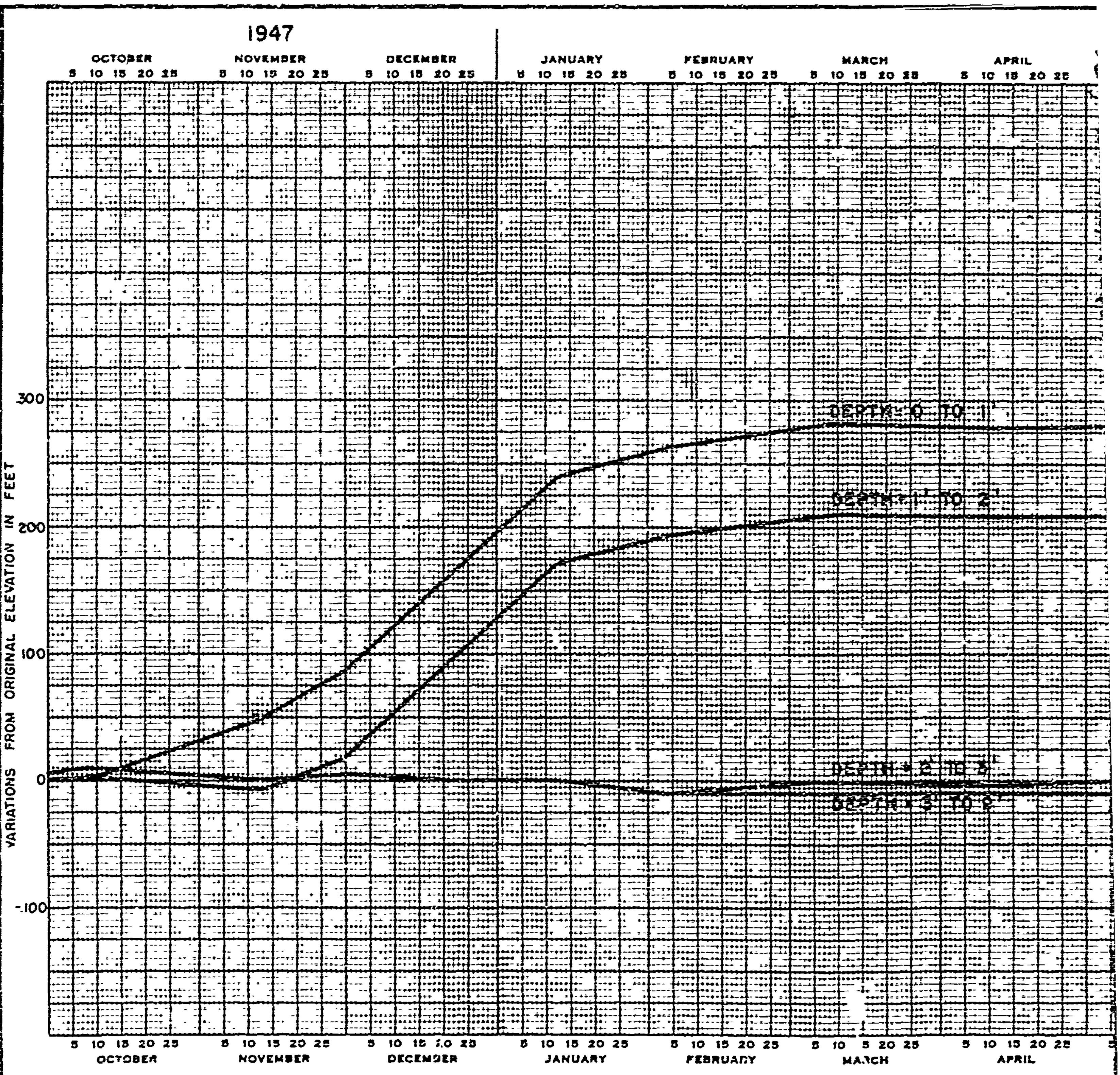


PERMAFROST INVESTIGATION
FIELD RESEARCH - FAIRBANKS, ALASKA

VERTICAL MOVEMENT OF
SWELLOMETER NO. I

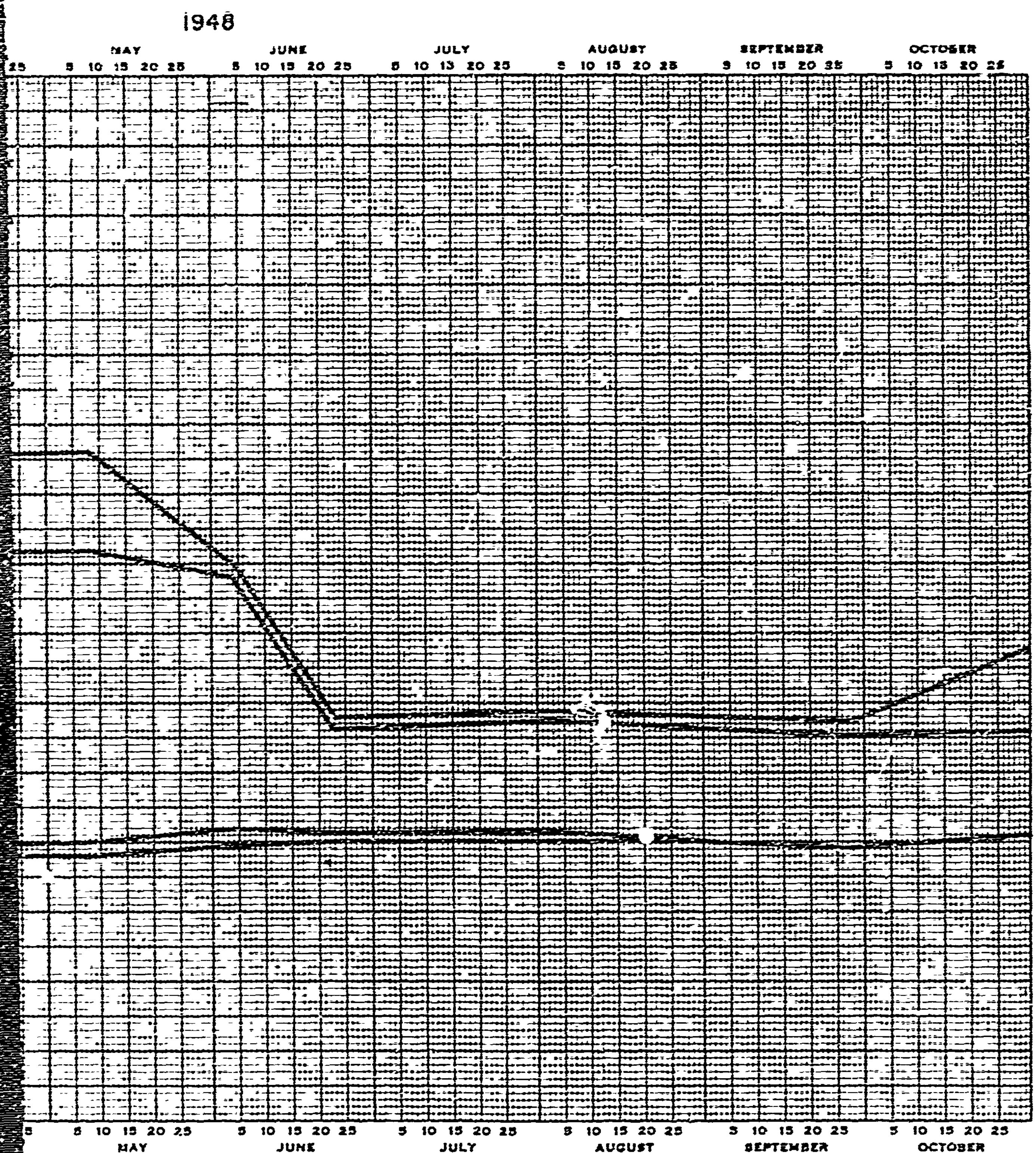
CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 40



1947
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
5 10 15 20 25
VARIATIONS FROM ORIGINAL ELEVATION IN FEET
300
200
100
0
-100
DEPTH: 0' TO 1'
DEPTH: 1' TO 2'

1.



PERMAFROST INVESTIGATION

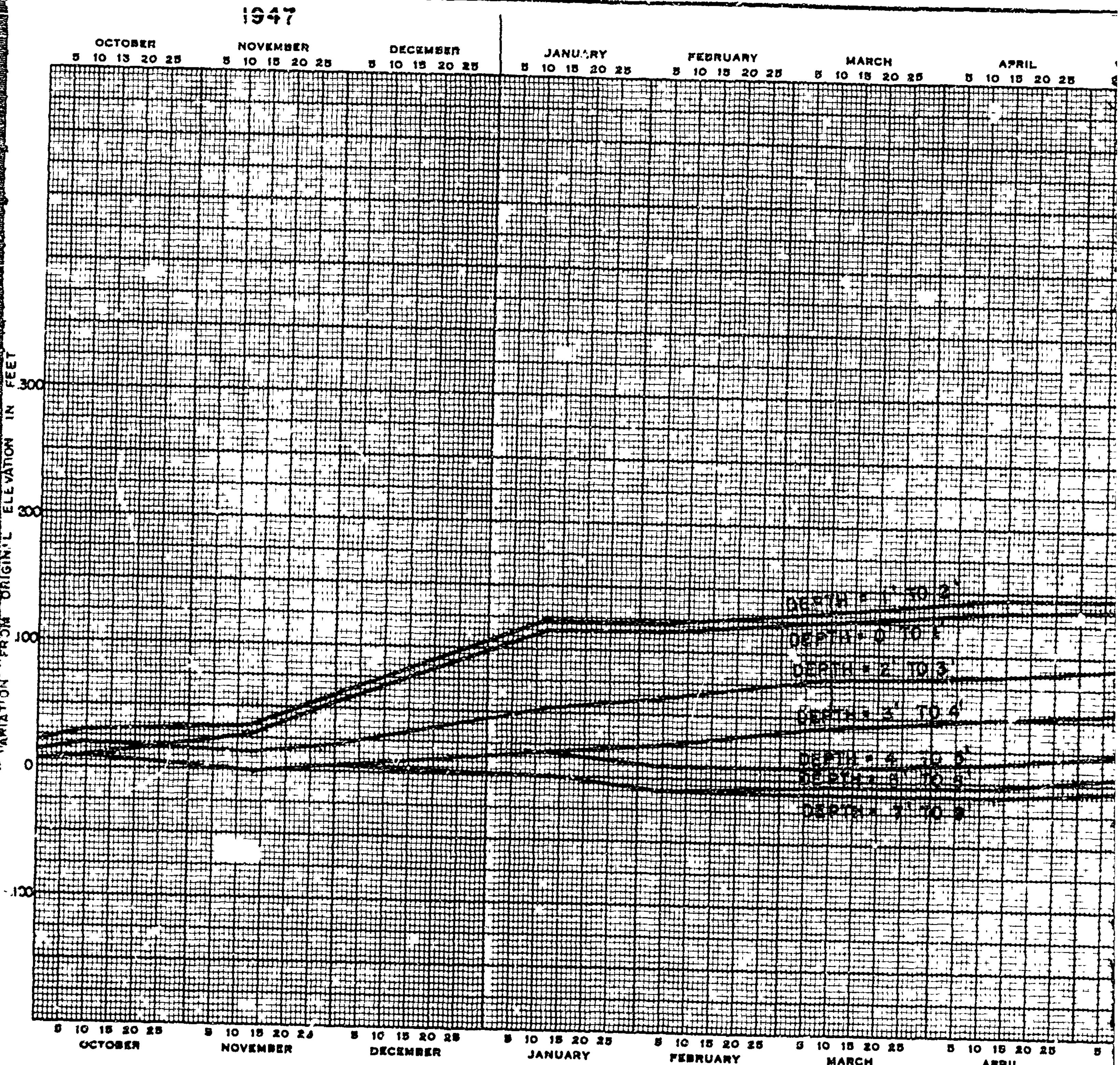
FIELD RESEARCH-FAIRBANKS, ALASKA

VERTICAL MOVEMENT OF
SWELLOMETER NO. 13

13

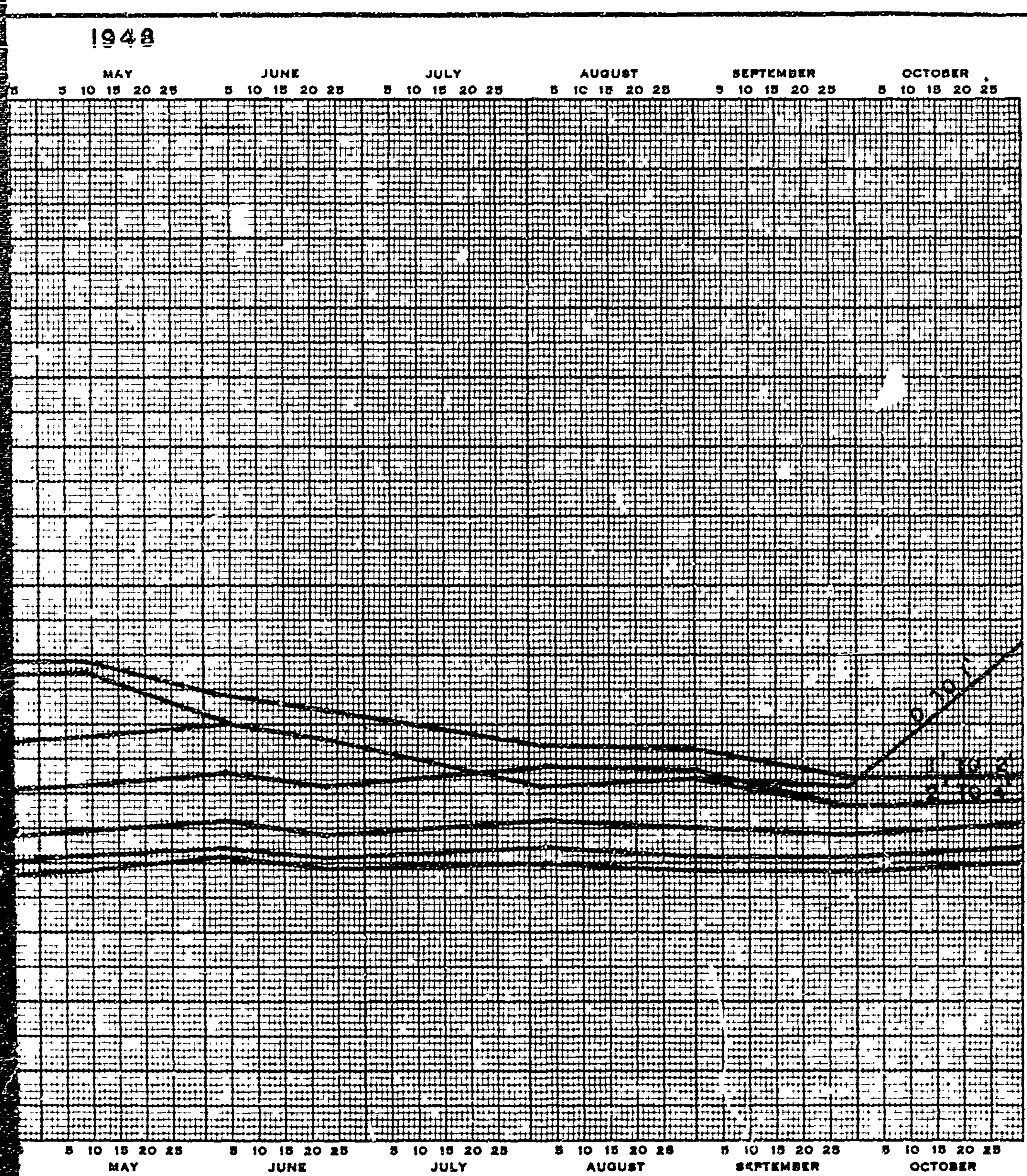
CORPS OF ENGINEERS, ST. PAUL, MINN. [illegible] 1950

PLATE 41



1947
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
5 10 15 20 25
VARIATION FROM ORIGINAL ELEVATION IN FEET
DEPTH = 1' TO 2'
DEPTH = 0' TO 1'
DEPTH = 2' TO 3'
DEPTH = 3' TO 4'
DEPTH = 4' TO 5'
DEPTH = 5' TO 6'
DEPTH = 7' TO 8'

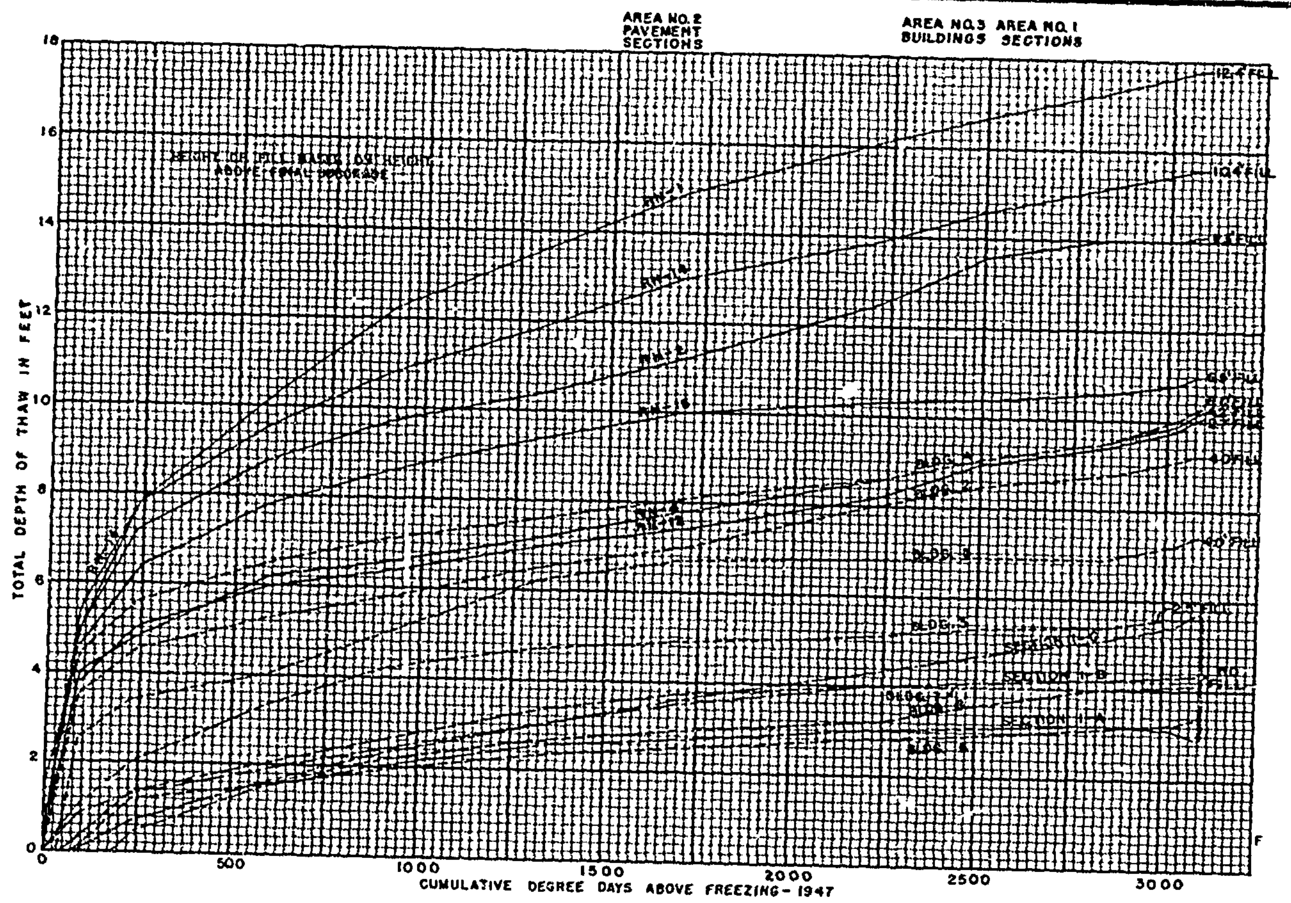
A



PERMAFROST INVESTIGATION
FIELD RESEARCH-FAIRBANKS, ALASKA
VERTICAL MOVEMENT OF
SWELLOMETER NO. 25

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

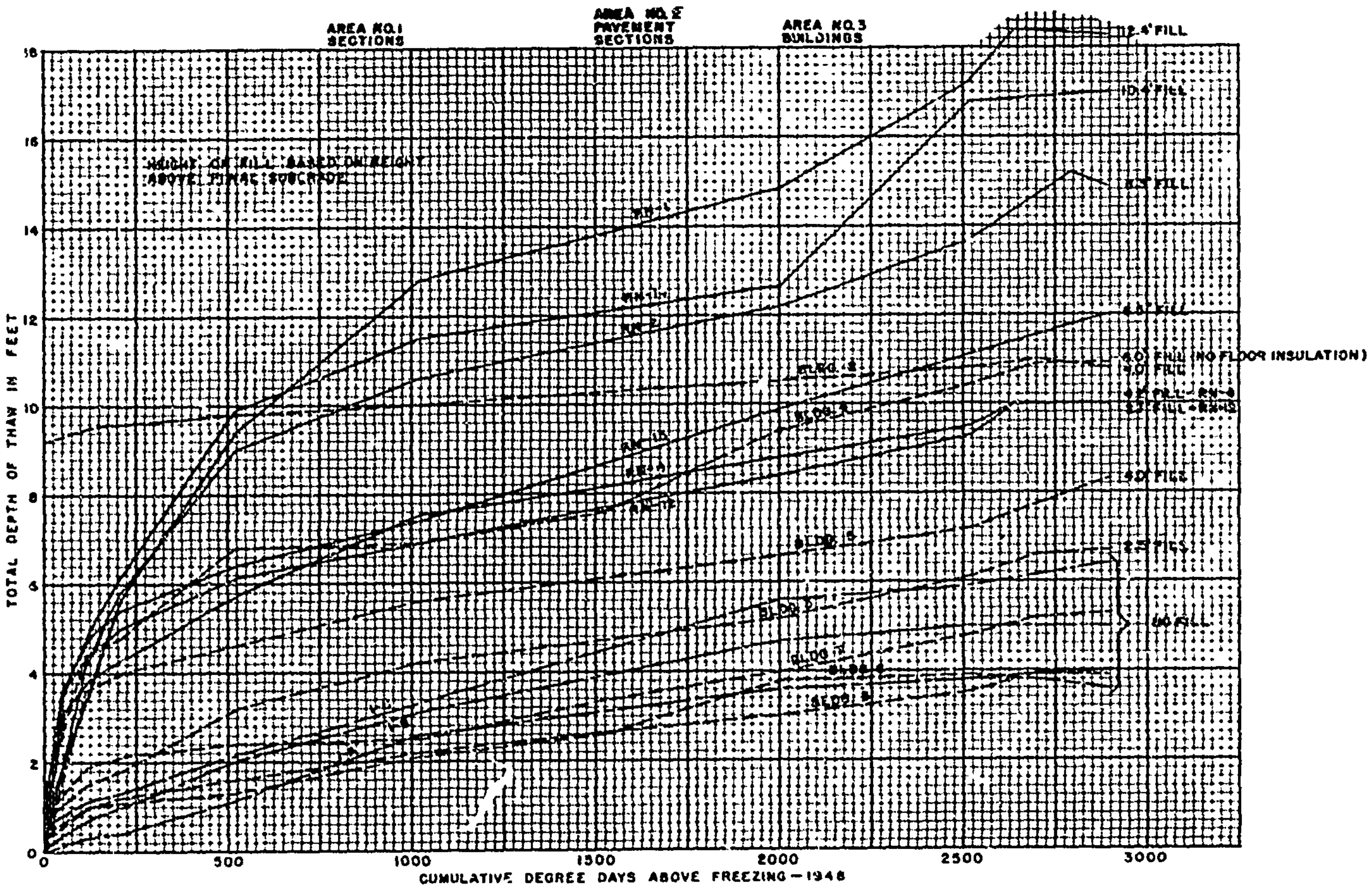
PLATE 42



PERMAFROST INVESTIGATION
FIELD RESEARCH - FAIRBANKS, ALASKA

DEPTH OF THAW IN VARIOUS FILLS
DURING 1947

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950



PERMAFROST INVESTIGATION
FIELD RESEARCH FAIRBANKS, ALASKA

DEPTH OF THAW IN VARIOUS FILLS DURING 1948

CORPS OF ENGINEERS, ST. PAUL, MINN. MAY 1950

PLATE 44